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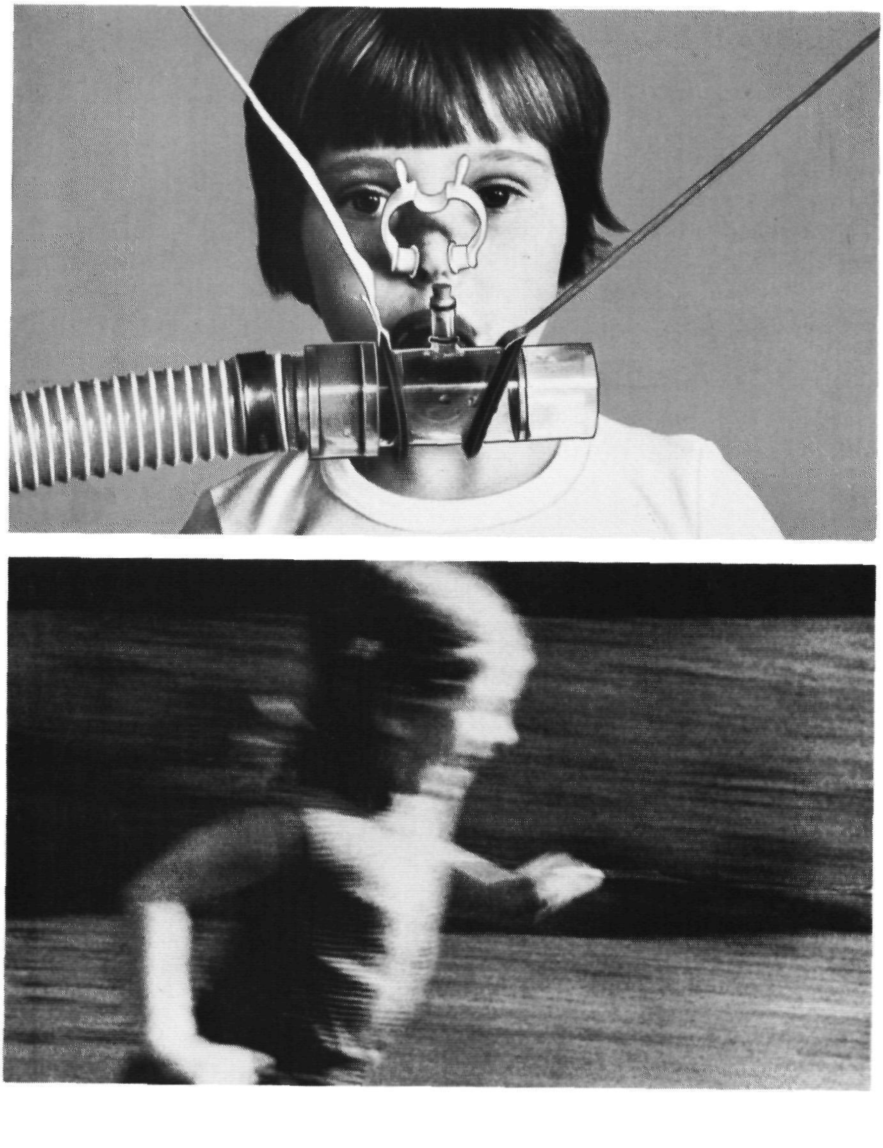
Aerobic power and daily physical activity in children

with special reference to methods and cardiovascular risk indicators

Wim H.M. Saris



AEROBIC POWER AND DAILY PHYSICAL ACTIVITY IN CHILDREN

- with special reference to methods and cardio-vascular risk indicators -

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PROEFSCHRIFT

ter verkrijging van de graad van doctor in de geneeskunde aan de Katholieke Universiteit te Nijmegen op gezag van de Rector Magnificus Prof Dr P G A B Wijdeveld volgens besluit van het College van Dekanen in het openbaar te verdedigen op donderdag 18 februari 1982 des namiddags te 4 uur

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ter nagedachtenis aan mijn vader.

Aan mijn moeder.

CONTENTS

VOORWOORD

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LIST OF SYMBOLS AND ABBREVIATIONS

G.V.O.	= gezondheidsvoorlichting en -opvoeding: health education
W.H.O.	= world health organization
P.A.	= physical activity
C.V.D.	= cardio-vasular disease
HDL	= high density lipoproteins
H.R.	= heart rate
H.R.max.	= maximum heart rate
E.C.G.	= electrocardiogram
$\dot{V}_{O_2}$	= oxygen consumption per time unit
$\dot{V}_{O_2}$ max. aerobic power	= maximum oxygen consumption per time unit
$\dot{V}_E$	= expiratory gasvolume per time unit
$\dot{V}_E$ max.	= maximum expiratory gasvolume per time unit
R	= respiratory exchange ratio
STPD	= standard temperature, pressure, dry (0^{o} C, 760 mmHg, relative humidity 0 %)
W170	= physical workcapacity at a heart rate of 170 beats.min^{-1}
PPC	= physical performance capacity
H.R.I.	= heart rate integrator system
H.R.M.	= heart rate monitoring system
E.E.	= energy expenditure
T.E.E.	= total energy expenditure per 24 hours
E.E. >50	= energy expenditure above 50 % of the aerobic power per 24 hours
E.E. >75	= energy expenditure above 75 % of the aerobic power per 24 hours
E.I.	= energy intake
Q.I.	= quetelet index
Sat.	= saturated fatty acids
PUFA	= poly unsaturated fatty acids
CHO	= carbohydrates

Conversion factors:

It was decided to use kcal as unit for energy according the demands of the Amer.J.clin.Nutr.

1 kcal ≈ 4.2 kjoule

1 $l.O_2.min^{-1}$ ≈ 341 watt ≈ 4.9 $kcal.min^{-1}$

Body weight is expressed in kg (force) instead of newton (1 kgforce ≈ 9.81 newton).

Chapter 1

GENERAL INTRODUCTION AND AIM OF THE STUDY

1.1. INTRODUCTION

In 1973 a Health Education Project (G.V.O.-project) was started in Nijmegen at the Institute for Preventive and Community Dentistry. The objective of this project is twofold:

- The development of instructional programs concerning various aspects of health for 4-12-year-old primary school children;
- To evaluate effects of the instructional programs on behavior and health.

The health problems handled in the program "To Your Health" are: Dental Care, Nutrition, Personal Health, Use of Health Services and Products, Environmental Care and Physical Activity.

What is the role of physical activity in relation to health? It is clear that people need a certain amount of movement in order to function optimally; but what is optimal in this respect? According to a recent survey by the Dutch Heart Foundation, 37 % of the population in The Netherlands believes that a lack of physical activity increases the risk of cardio-vascular disease (Dekker, 1980). The same survey indicated that 50 % of the family doctors considered the level of physical activity to be an important risk indicator. It is not surprising that the decreasing physical activity, due to technological developments, in recent decades has been generally believed to be connected with the increase in cardio-vascular disease. Is there a relation between these two developments?

The extent to which physical activity and physical performance contribute to the whole complex of cardio-vascular disease in adults will be described through the review of a number of studies in paragraph 1.2.1. The extent to which these aspects are of importance at an early age will be discussed in paragraph 1.2.2. In order to evaluate the G.V.O. Health Education Program it was necessary to develop and validate methods for measuring physical activity and physical performance. An introduction into the problems involved in measuring these two parameters in children is given in paragraphs 1.3 and 1.4. Finally the goal and scope of this study will be described in paragraph 1.5.

1.2.1. DAILY PHYSICAL ACTIVITY AND PHYSICAL PERFORMANCE CAPACITY RELATED TO CARDIO-VASCULAR HEALTH IN ADULTS

The first studies in this area were directed primarily at physical activity (P.A.) in occupational work. In a classic study, Morris et al. (1953) found that the incidence of heart attack of bus drivers was twice as high as that of bus conductors on London double-deckers. The amount of physical activity was higher for the conductors who walked to the upper deck several times a day. However, Morris et al. later published in 1956 that the bus drivers already had larger belly-girths at the start of their jobs and therefore had a greater propensity for obesity. This reveals one of the greatest problems in this type of research: a relationship between two factors does not necessarily mean that it is also a causal one. Finding a negative relation between physical activity and cardio-vascular disease could be explained by self-selection: for example, people with a higher risk for cardiovascular disease (C.V.D.) might have a tendency to accept jobs in which little physical activity is necessary. To deal with this problem, Morris (1975) formed groups of bus drivers and conductors with the same belly-girths at the moment they began working at these jobs. The conductors in these groups again had a lower incidence of fatal heart attack. Froelicher and Oberman published in 1972 a critical review of all the important studies since Morris. They concluded that physical "inactivity" as risk indicator is not as important as hypercholesterolemia, hypertension, and cigarette smoking. Besides a number of studies showing a positive relationship between the level of physical activity and the risk of C.V.D., there were also studies which failed to show such a relationship. They believed, however, that there was enough evidence on hand suggesting that physical activity can be regarded as a "protective" factor against C.V.D. Large-scale randomized, controlled studies are, therefore, justified despite the high costs, and time investment that these studies bring with them.

A number of subsequent studies have been published which deserve attention. Ilmarinen and Fardy (1977) were the first to do a randomized controlled intervention study, performed on a group of 166 male executives, ages 35-59 years. The training program, one session a week, lasted 18 months. At the end of this period, the aerobic power of the experimental subjects had increased, but no differences were shown between the levels of separate risk indicators such as bloodlipids and body fatness, for the experimental and control groups. There were also no positive changes in the physical activity pattern nor in the level of risk indicators for the experimental group after two years. Contrary to studies before 1972, recent studies have included leisure-time as well as occupational physical activity. Morris et al. (1980) performed a prospective study with a large group of office workers. The incidence of C.V.D. in the group which participated in intensive leisure time physical activity was 50 % lower than that in the group which was inactive during leisure hours. In the discussion following the publication, the question was raised about the role played by self-selection (Jarret, 1981; Burch, 1981). Although no proof could be given that this was not the case, the differences between the active leisure time and inactive leisure time groups with a similar risk profile were such that Morris (1981) stated:

"Vigorous exercise is a natural defense of the body, with a protective effect on the aging heart against C.V.D.".

The Dutch study by Magnus et al. (1980) produced the same results; people who regularly bicycled, walked, or worked in the garden were half as often the victim of a first myocardial infarction or fatal coronary attack.

Furthermore, there are a number of studies published which show without exception that a better physical performance capacity corresponds with a lower risk profile concerning body fatness, bloodpressure and bloodlipids (Gyntelberg, 1974; Cooper et al., 1976; Erikssen et al., 1978).

Finally, in a very recent study, Ilmarinen et al. (1980 and 1981) investigated the effects of physical activity during occupational work and leisure time on the physical performance capacity and on the level of various risk indicators. They concluded that leisure-time activities were more important than occupational activities for maintaining a good physical performance capacity and a low risk profile, concerning bloodlipids and body fatness.

What are the possible mechanisms for the protective effect of physical activity? A large number of factors are mentioned and discussed (Fletcher and Cantwell, 1974) such as:

- an increased physical performance capacity;
- increased myocardial vascularity;
- reduced blood coagulation and increased fibrinolytic capability;

- reduction of heart rate and bloodpressure;
- reduction of percentage of body fat;
- increased insuline sensitivity;
- increased HDL/total cholesterol ratio and reduction of triglycerides;
- psychological factors such as decreased sensitivity for stress, etc.

A generally accepted guideline for sufficient physical activity is : dynamic exercise 3 to 5 times a week for a period of 15-60 minutes at an intensity of 50-85 % of the aerobic power (E.E.C./W.H.O. Commission, 1977; Amer.College of Sports.Med., 1978).

In summary, it can be said that a reasonable amount of physical activity can have a positive effect on the quality of life. Furthermore, there are indications that physical activity of a reasonable intensity has a protective effect against C.V.D. However, a clear statement regarding this is not yet possible particularly because of the methodological problems involved in epidemiological research, such as the quantification of physical activity and the lack of randomized control trials.

1.2.2. DAILY PHYSICAL ACTIVITY AND PHYSICAL PERFORMANCE CAPACITY RELATED TO CARDIO-VASCULAR HEALTH IN CHILDREN

Contrary to the research with adults, investigations into the level of possible risk indicators in children have only started in the past few years. We are just beginning to realize that a fundamental approach for preventing chronic illnesses such as C.V.D. should begin at childhood. It is in these early years that habits are formed which could later lead to manifest forms of C.V.D. It is important, therefore, to know the extent to which certain risks are already measurable in childhood, or, in other words, the extent to which indicators can be considered risk factors for the possible development of C.V.D. at a later age.

Unlike adults, children, and especially young children, have a natural need for movement which slowly but surely decreases at 12-15 years of age. This movement is absolutely necessary for normal growth and development. It is clear that there are differences in the amount of physical activity that children get. However, there is little known about the degree to which these differences affect growth and development and the possible development of risk indicators for C.V.D. at an early age or during adulthood (Rutenfranz, 1980).

Pařízková (1974) followed active and inactive boys for a 7-week period and found that the active boys had a higher growth rate and a lower percentage of fat compared to the inactive boys. As discussed in paragraph 1.2.1 the findings may have been influenced by self-selection since there were already significant differences in body composition among the boys at the start of the study. The only type of research in which the effects of physical activity have been investigated in a justifiable way are intervention studies into the effect of physical education on physical development. However, the results of such studies show no clear differences in pre-puberty children (Kemper et al., 1974; Shephard, 1981). In general, the evaluation criteria used can be divided into 3 groups: 1. the cardio-respiratory capability in particular, the aerobic power; 2. muscle performance, such as strength; and 3. sensomotoric development, such as co-ordination. In view of the nature of this study, we will confine the discussion to the effects on the cardio-respiratory system. In the studies by Kemper et al. and Shephard, the extra physical education lessons had no effect on the aerobic power. Also no improvement of aerobic power was found in studies in which 4-12-year-old children were endurance trained: Schmücker and Hollmann (1973), Gilliam et al. (1980) and Yoshika et al. (1980). These findings were contrary to studies with adolescents (Watson, 1979) and adults (Ekblom, 1969) where clear, positive effects could be established from endurance training on aerobic power. The amount and intensity of the endurance training and extra lessons in physical education for pre-puberty children was probably small compared to the total amount of physical activity during the day (Stewart and Gutin, 1974).

Another important aspect is the influence of genetic characteristics. A study by Klissouras (1971) with fraternal and identical twins between the ages of 7 and 13 years indicated that 93 % of the difference in aerobic power could be explained by genetic differences and only 7 % could be explained by differences in physical activity. This may mean that differences in aerobic power among young children are largely due to genetic influences and that physical activity has relatively little influence on aerobic power.

There are a number of phases in which changes in physical activity can be expected to occur during childhood, such as at the transition from kindergarten to elementary school where the children must sit for longer hours. The sparce data available, show that this change seem to be of no consequence for the level of aerobic power (Åstrand, 1952). The hours of physical inactivity are possibly compensated by activity during recesses and after-school hours. Heart rate registrations of children in this age group during a 24-hour period as shown by Lange Andersen et al. (1978) and Saris (1981) indicate that this indeed may be the case. Considerably higher heart rates up to 200 beats.min^{-1} were recorded during these periods. A study by Ilmarinen et al. (1980) with older children show that a changed activity pattern leaving the school period to go to work does indeed influence the aerobic power. They point out that the aerobic power decreases because less time is then spent on sports. From these sparce data, it can be expected that differences in physical activity between post-puberty children may indeed result in differences in aerobic power.

What are the connections between daily physical activity and performance capacity and known risk indicators such as hypercholesterolemia and obesity? As generally known, a high level of these risk indicators can be shown to be present during childhood. V.d. Haar and Kromhout (1978) showed that 25 % of a large group of Dutch children had a high level of cholesterol and 9 % were too fat. The relationship between inactivity and obesity has received particular attention, partly due to the classic research of Bullen et al. (1964). They showed through a motion picture sampling that obese girls were less active than non-obese girls of the same age. The important question remained whether the obese children ate more and/or move less than non-obese children. Waxman and Stunkard (1980) performed a study on obese boys. The physical activity measured by the time-sampling technique was lower than that of non-obese boys. The energy expenditure was, however, greater. The difference between energy consumption and expenditure was also more positive in the obese groups, indicating that the obesity is related to a lower activity level and a higher energy intake.

The only research we know of in which the level of risk indicators as well as physical activity and aerobic power are measured is a study by Kemper (1980) with 13- and 14-year-olds. There were no significant differences in serum cholesterol, bloodpressure and percentage of fat between children grouped according to a high or low score obtained from an activity questionnaire or pedometer score. There was, however, a significant difference in aerobic power between the two groups of boys. Boys with a high activity score had a higher aerobic power.

Studies in which the level of aerobic power alone was involved were those of Wilmore and McNamara (1974) and Gilliam et al. (1977) with 8-12-year-olds in the U.S.A. A low aerobic power in 5 to 10 % of the children (<42 and <32 $\dot{V}_{O_2}$ max.ml.kg^{-1}min^{-1} respectively) was indicated as a risk factor by the authors. Co-variant analysis revealed no clear relationships between the various indicators.

In summary, it can be concluded that even at a young age (younger than 13-14 years) children may already have a certain degree of risk for the development of C.V.D. during adulthood if the same levels of the risk indicators for adults are also applicable for children. It is unclear to what degree inactivity and a low physical performance capacity contribute to this level of risk in children. As in adults, it is suggested that the amount of physical activity and the level of aerobic power in children should not be considered a risk for the development of C.V.D. at a later age, but should be viewed as positive health indicators.

1.3. THE ASSESSMENT OF THE DAILY PHYSICAL ACTIVITY IN CHILDREN

Measuring daily activity is one of the most difficult tasks for the physiologist (Garrow, 1974). Obtaining this information from children is even more difficult than from adults. A problem encountered in measuring physical activity is the presence of contradictory aims. On the one hand, it is desirable to record the normal daily movements of a child, which usually means that the person in question must be burdened with equipment for measuring a number of body functions. On the other hand is the desire not to pose a hindrance to the childs normal daily activities.

A factor in large-scale studies is the need for a method which is simple, low-cost and not time-consuming so that large samples can be measured. In general, however, 24 hours is considered a minimum amount of time (Lange Andersen et al., 1978).

Energy Intake

The physical activity can be quantified by determining energy intake. Various methods are in use and there is extensive literature about reliability and practical problems (Garrow, 1974). The methods can vary from weighing and analyzing double portions to asking about what was eaten in the past 24 hours. This latter method, the 24-hour recall, is the most practical method for large-scale studies.

Besides the methodological problem concerning the validity of the individual and mean values, there is the problem of assuming that energy consumption and expenditure are in equilibrium, an assumption which is only correct for measurements over a longer period (1 week) and when the weight and body composition are constant. This assumption is certainly not correct for one day measurements (Acheson et al., 1980).

Oxygen Consumption

It is possible to measure energy expenditure by determining the oxygen consumption, assuming that the physical exercise throughout the day is almost entirely aerobic (Åstrand and Rodahl, 1977).

Besides obtaining accurate data when measuring oxygen consumption over longer periods of time, it is also possible with this method by sampling over shorter periods of time to obtain information about the intensity of the exercise. Douglas bags can be used, although, this is not always practical for field research. For this reason equipment was developed at the end of the last century, to measure oxygen consumption under field conditions (Zuntz, as cited by Christensen, 1958) (see Figure 1). Modern versions of this equipment are the K.M. respirometer (Kofranyi and Michaelis, 1949), the Oxylog (Humphrey and Wolff, 1977) and the recently developed MISER (Eley et al., 1978). Although the oxygen consumption method is accurate and valid (Consolazio et al., 1963) there are clear disadvantages for long-range studies. A mask or mouthpiece and nose clamp must be worn along with the device itself. Therefore, the measurement period cannot be longer than 20-30 minutes and the method is unsuitable for children.

An alternative method is described by Durnin and Passmore (1967) in which oxygen consumption is measured for a few characteristic activities and an activity diary is kept as well. The daily energy expenditure is predicted

Figure 1. The first portable respirometer to measure energy expenditure under field conditions (Zuntz, as cited by Christensen, 1958).

with this data and energy expenditure tables. A disadvantage of this method is that the accuracy is dependent upon the co-operation of the subject who must note his own activities (Acheson et al., 1980).

Heart Rate Recording

Because it is not always possible to measure oxygen consumption during daily activities and because the combination of oxygen consumption measurement and daily activity diary is not entirely satisfactory, a physiological parameter was sought as an indicator for physical exercise. The heart rate seemed the most likely choice (Bradfield, 1971). The oxygen intake is predicted from the measured heart rate of a person, using an individually assessed relationship between heart rate and oxygen consumption at standardized workloads. There are, however, certain disadvantages with this prediction method. The relationship between H.R. and oxygen consumption is dependent upon the type of exercise (arm or leg, sitting or standing). Furthermore, the relationship is less accurate for heart rates below ca.

110-120 beats.min^{-1} which is the case in the largest part of the daily activities. There were but few available data over the validity of the method at the start of this study.

The heartbeat can be registered in 3 ways: 1. by telemetry (Schäcke et al., 1972) (the disadvantage of this method is that the researcher must remain in the area of the subject); 2. by using a tape recorder (Rutenfranz et al., 1977) (the disadvantage of the first types of tape recorders were the size and weight which made this less suitable for children); and 3. by using solid-state recorders (see Chapter 4) (the disadvantage is that no information about the E.C.G. can be obtained).

Movement Counters

Another form of measuring physical activity is that in which movements of the body - in particular of the extremities - are recorded. Well known in this area are the pedometer which counts steps, and the actometer which acts on force of the movement: a modified wristwatch (Schulman and Reisman, 1959).

Both pieces of equipment are small, simple, low-cost and can be worn for long periods of time without hindering the child. No information was available at the beginning of the study concerning the accuracy and validity of this equipment.

Questionnaires

There are the methods in which the daily physical activities are recorded by writing them down in a diary. The most well-known is the activity diary in which the energy expenditure over a period of 24 hours can be calculated from activity and energy expenditure tables from Durnin and Passmore (1967). The accuracy is dependent upon the co-operation of the subject and for this reason the method is unsuitable for children under 15-16 years of age. According to an inventory performed by the Institute of Occupational Health in Helsinki (Heinilä et al., 1965) retrospective questionnaires about performed activities are often applied. There is, however, very little research published over the reliability and validity of this method (Montoye, 1975; Morris et al., 1973). An extra problem in the research with children is the disadvantage to have only secondhand information from the parents or teacher.

Observations

Time and motion observation (Barnes, 1963) is a good alternative for the activity diary method but is very time-consuming and again unsuitable for application when studying subjects who may move about freely.

In summary, it can be said that in order to measure the daily physical activity, a number of requirements must be met. The most important requirements are: the measurement method must not influence normal activity; it must give a valid estimation of the activities; it must be applicable over a minimum period of 24 hours for large groups of children. There are 3 methods which were considered to be applicable to this study within the framework of the above requirements: heart rate monitoring, movement counters and activity questionnaires. At the start of this study there was little or no information about these methods nor about their accuracy and validity.

1.4. THE ASSESSMENT OF THE PHYSICAL PERFORMANCE CAPACITY IN CHILDREN

By physical performance capacity, we mean the aerobic power (maximum oxygen uptake per time unit) which can be considered to be a most relevant factor in this respect (Åstrand and Rodahl, 1977). To reach the level of aerobic power, a person must perform maximal exercise with large muscle groups, in a standardized way. A number of recommendations have been made in this regard by the W.H.O. (Shephard et al., 1968). One of the most important recommendations was that the treadmill was the most suitable equipment for testing children under the ages of 10-12 years. Walking is certainly a natural form of movement for young children. Furthermore, the treadmill has the advantage that the work that the child must do is prescribed, unlike the bicycle ergometer where the child must regulate the pedalling rate himself, a problem especially for younger children. This can be partially solved by working on an electronically braked bicycle ergometer where the workload is constant for a large pedalling rate range (Vos et al., 1978). There is, however, another objection to testing children on a bicycle ergometer. The usual types are too large for children under 10-12 years of age even when the saddle is in the lowest position. An advantage of the bicycle ergometer over the treadmill is the minimal chance of injuries during the exercise. To prevent falling on the treadmill, a safety belt should be used or the researcher should hold the child without providing support.

The treadmill was chosen in this study for children between 4 and 12 years of age. The choice of a test program on the treadmill is dependent upon whether the aerobic power is to be measured or predicted. A number of tests have been designed for directly measuring the aerobic power, varying from those in which steady state workloads at different levels up to the maximal are performed on different days (Åstrand, 1952), to schedules in which the workload is increased every minute to the point of exhaustion (continuously increasing workload) (Balke and Ware, 1959).

The brief continuous tests are by far preferable for children (Shephard, 1968), since they can become bored by long testing and may no longer be prepared to continue. One important aspect of this type of test is the degree of increase in workload : an increase in workload of 20 watt equals approximately 10 % of the maximal power of a 15-year-old, but approximately 50 % of that of a 5-year-old (Godfrey, 1974). For this reason, the increase in workload per kg body weight is proposed for bicycle ergometer tests (Macek and Vãvra, 1971). This procedure has not been applied for the treadmill until now. More general protocols have been developed which are either suitable for children (Skinner et al., 1971) or for adults (Balke, 1959) but not for both. We believe the only protocol suitable for both children and adults is that of Bruce et al. (1973).

For measuring the oxygen consumption it is necessary to collect the expired air via a mouthpiece while the nose is clamped. This can sometimes be a problem for young children. The relatively large mouthpiece is difficult to keep in the mouth which makes determination of oxygen consumption impossible. Furthermore, the younger children often tend to stop before the maximum is reached: running at a maximal level for an extended period (1-2 minutes) is a form of exercise which does not occur during normal daily exercise at a young age. Then, there are a number of general problems, such as the need for equipment to measure O_2 and CO_2, the safety measures, the need for a defibrillator and the duration of the test, making the maximal method less suitable for measurements in the field. That is why submaximal tests have been developed for predicting the aerobic power. Three types of methods will be discussed here.

In the first method, the oxygen consumption and the heart rate are measured during a number of submaximal workloads. The aerobic power can then be calculated from the linear regression equation between oxygen consumption and heart rate for a given maximal heart rate. Using this method Hermansen and Oseid (1971) among others obtained values which were about 15 % lower than the actual measured results for a group of 13-14-year-olds. Davies et al. (1972) found mean $\dot{V}_{O_2}$ max. values that were about 20 % lower than the direct $\dot{V}_{O_2}$ max. results. For this reason, the underestimation of the aerobic power must be taken into consideration when using this method.

In the second method the oxygen consumption is not measured: the aerobic power is estimated using the workload and the heart rate and a standard relationship between oxygen consumption and workload. This method was developed only for the bicycle ergometer (Åstrand and Rodahl, 1977).

The third method of estimation is to find the workload at which a heart rate of 170 is reached during a continuously increasing workload test, the so-called "Physical working capacity 170" (W170) (Rutenfranz, 1964). The workload at 170 beats.min^{-1} is the indicator for the level of the aerobic power. Comparative measurements have been made by Mocellin et al. (1971) and Lindemann et al. (1980) and others. They found correlation coefficients of 0.7-0.8 for the W170 value and the aerobic power. However, these studies are limited to the bicycle ergometer. As far as we know, there are no published studies about the validity of the W170 for predicting the aerobic power on the treadmill.

In summary, it can be said that the treadmill is the most suitable form of physical exercise for testing the physical performance capacity of young children. It is preferable to measure the aerobic power. However, the maximal test is sometimes difficult to perform for young children. Furthermore, the method is time-consuming and a well-equipped laboratory is necessary. The indirect determination of the aerobic power using data from submaximal workloads seems to be a reasonable alternative for measurements in the field on large groups of children. At the beginning of this study there were, however, no adequate treadmill procedures available for our purpose.

1.5. CONCLUSIONS AND AIM OF THE STUDY

It can be concluded from the preceding literature-review that, at the start of the G.V.O.-project, little or nothing had been developed with respect to the quantification of the daily physical activity and the determination of aerobic power in young children. One of the first aims of the project was therefore the development and validation of methods and techniques for evaluating the daily physical activity and the aerobic power of 4-12-year-old children.

In *Chapter 2* a report is given of the studies performed to develop a submaximal treadmill exercise test. We decided to develop several methods for the evaluation of the daily physical activity : in this way a clearer picture could be obtained of the possibilities for measuring physical activity in children. In *Chapter 3*, the results of the measurements with movement counters are discussed. The heart rate method is discussed in detail in *Chapter 4*. During the period in which the techniques were tested, the ideas about measuring physical activity in children were a continual subject of critical evaluation. This had led to a visable development in the methods and the interpretation of results in the publications. For example, in Chapter 4.1 the heart rate itself is assumed to be a good indicator of the degree of physical activity, while in Chapters 4.3 and 6, this idea is considered incorrect.

Subsequent to this period of development, the G.V.O. study was started in 1976 at approximately 30 elementary schools in the Nijmegen area. Half of these schools participated in the G.V.O. education program. The other schools were controls.

Measurements were taken in 1977, 1979 and 1981 to collect information about developments in health status and habits such as nutrition and physical activity. This information is especially important in order to take the actual situation, regarding the health of these children, into account when designing the G.V.O. program. A final evaluation will take place in 1983.

All the studies were done in co-operation with the workgroup "Exercise Physiology" of the University of Nijmegen. From discussions within this group as well as with outside experts, it was gathered that there is a great need for reference values for the physical performance capacity of children. A study to obtain this data was started in 1980. The preliminary results are discussed in *Chapter 5*. In order to be able to make a comparison with data from the G.V.O.-project, we have limited ourselves to the results of the aerobic power[1].

The data from the G.V.O.-project with 6, 8 and 10-year-old children are discussed in *Chapter 6*. The connection between aerobic power and physical activity as well as possible relationships with the levels of some C.V.D. risk indicators are also discussed in further detail.

[1]This project was made possible by a grant from the Dutch Heart Foundation: Grant No. 79.015.

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Chapter 2

ESTIMATION OF W170 AND MAXIMAL OXYGEN CONSUMPTION IN YOUNG CHILDREN BY DIFFERENT TREADMILL TESTS

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SUMMARY

Several bicycle ergometer tests have been developed for the estimation of the physical performance capacity in older children. However, the treadmill is usually preferable for children under 10 years of age. The aim of this study was to compare continuous and intermittent treadmill tests with respect to the measurement of submaximal levels of heart rate (H.R.) and oxygen consumption ($\dot{V}_{O_2}$). We also wanted to compare the calculated $\dot{V}_{O_2}$ max., obtained by the continuous treadmill test and measured $\dot{V}_{O_2}$ max. in young children.

5-Year-old children (*n*=22) were alternatively assigned to multistage treadmill tests: 2 trials of a continuous test (step-2), starting horizontally and increasing the gradient 5% every 2 minutes and 1 intermittent test in 2 sessions (every 6 minutes). Submaximal values for H.R., $\dot{V}_{O_2}$ and ventilation ($\dot{V}_E$) were measured by the Douglas-bag method. There were no significant differences between the continuous and intermittent tests with respect to H.R., $\dot{V}_{O_2}$ and $\dot{V}_E$ at all workloads. Furthermore, no differences could be found between the two trials of the continuous tests. The coefficient of reliability was higher than 0.9 for all workloads except for the 0 % gradient.

The method was validated with a group of 8-year-old boys (*n*=41) by comparing the indirect $\dot{V}_{O_2}$ max. and direct $\dot{V}_{O_2}$ max. values. The indirect $\dot{V}_{O_2}$ max. was calculated from the results of the continuous step-2 test and the direct $\dot{V}_{O_2}$ was measured by the Bruce treadmill test.

The submaximal step-2 test resulted in a mean indirect $\dot{V}_{O_2}$ ml.kg^{-1}min^{-1}

of 56.9 ± 15.0 compared with a measured value of 55.4 ± 7.9. The mean difference (± S.E.) between indirect and direct $\dot{V}_{O_2}$ max. was ± 0.78 ± 1.59. The coefficient of validity was 0.73. The W170 (expressed in % slope at which a heart rate of 170 was reached) had a considerably lower coefficient of validity (0.57).

In agreement with other studies with older children using a bicycle ergometer, the estimated and measured average $\dot{V}_{O_2}$ max. are in good agreement with the results for younger children on the treadmill. However, there are considerable intra-individual differences especially when the W170 value is used.

Key words: Submaximal and maximal workload - Prediction of maximal oxygen consumption - Treadmill - Children.

INTRODUCTION

The G.V.O.- health education project - is an intervention study of the effects on behavior and health of an integrated health education program for 4-12-year-old children during the entire elementary school period. One of the facets handled in this program is the relationship between physical activity, physical performance capacity and health.

For this reason an exercise test was included in the investigations.

The directly measured maximal oxygen consumption is generally accepted as the most precise index of physical performance capacity (Åstrand, 1977). This method of all-out testing is time-consuming and requires the full co-operation and motivation of the subjects. The method is less suitable for our study because of the large number of children to be measured and because the 4- to 7-year-olds are difficult to motivate. For these reasons, a submaximal exercise test was chosen to predict maximal oxygen consumption. However, at the time of the study, no submaximal procedures were published for young children (4- to 7-years-old). Most tests had been performed on a bicycle ergometer (Mocellin et al., 1971) whereas the treadmill is generally preferable for children under 10 years of age. The decision was made to design an experiment with 5-year-old children to establish a suitable sub-maximal treadmill procedure for predicting physical performance capacity.

This procedure (continuous test) was also validated with a group of somewhat older children (8 years of age), using the measured maximal oxygen consumption obtained through the Bruce treadmill test.

METHODS

First Experiment

The subjects were healthy school boys and girls (n= 11 and n=11 respectively) from a class of a Nijmegen area school, ages 5 to 6 years. The children came to the laboratory 4 times within a 3-week period to complete a submaximal treadmill test. The children, who were familiar with walking on the treadmill, were randomly assigned to begin with one of the 2 different tests.

Starting horizontally, the treadmill gradient was increased 2.5 degrees (4.6 %) every 2 minutes (step-2) to a maximum of 10 degrees (18.3 %). The constant walking speed was 4.0 $km.hr^{-1}$.

To test the reliability of this method, 2 trials were completed for the continuous test (step-2.1 and step-2.2). A test was also performed in which the above gradients were increased every 6 minutes. To reduce the total walking time (30 minutes) per session, this test was performed on two separate mornings - the first session included 3 workloads of 6 minutes each at gradients 0, 5 and 10 degrees (0, 9.2 and 18.3 respectively) and the second session at 2.5 and 7.5 degrees (4.6 and 13.8 % respectively). The walking speed was 4.0 $km.hr^{-1}$.

The expired air was collected in Douglas bags during the last minute of every load. The E.C.G. was recorded continuously and the heart rate was calculated during the air collection period. The collected volume of expired air was measured with a Tissot-spirometer. The CO_2-content of the expired air was determined by means of infra-red absorption and the O_2 was measured on a paramagnetic basis. Statistical analysis was performed with the Hotelling test. The results of the different loads are combined in this statistical analysis (Morrison, 1967).

Second Experiment

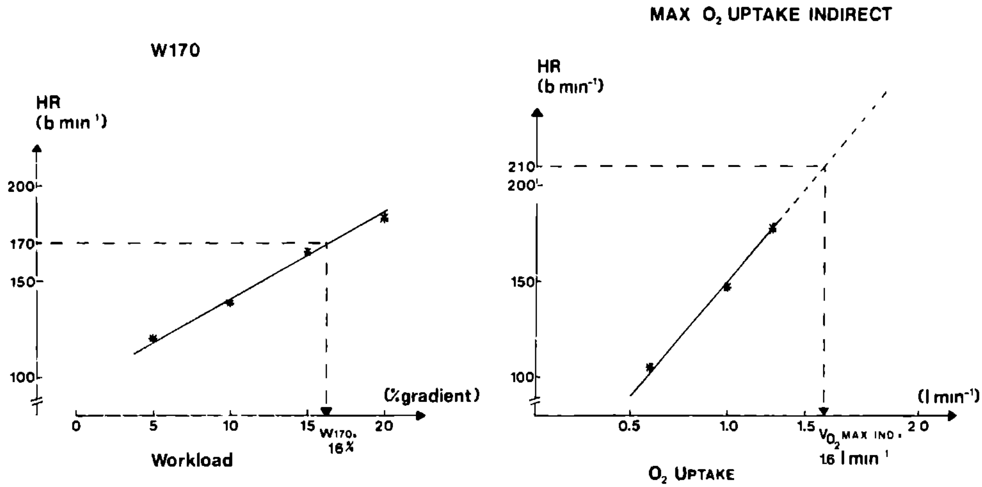
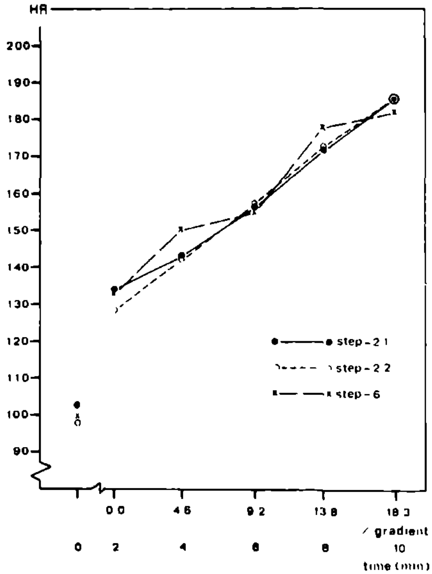


Figure 1. Calculation of W170 from heart rate and increasing workload and maximal oxygen consumption from heart rate and oxygen consumption.

The chosen step-2 test was validated by comparing the results of this test with the direct maximal oxygen consumption. 41 Healthy 8-year-old boys performed both the submaximal test and the maximal Bruce test (Bruce et al., 1963). The 41 boys were selected from the total research population of the G.V.O.-project of approximately 800 children (Saris et al., 1980) on basis of their W170 scores at 5-6 years of age and 7-8 years of age. These selected children achieved a high, average or low W170 score at both ages.

Unlike the chosen step-2 test, the gradient in this W170 test is increased (for practical reasons) 5 % instead of 2.5 degrees every 2 minutes, starting horizontally. The walking speed for this age group was a constant 4.5 km.hr^{-1}. The testperiod ended when a heart rate of about 170 beats.min^{-1} was reached; the workload was expressed in the percent gradient at which a heart rate of 170 was reached (Figure 1). Expired air was collected in Douglas bags during the second minute of each of the 3 highest working loads and analyzed as described.



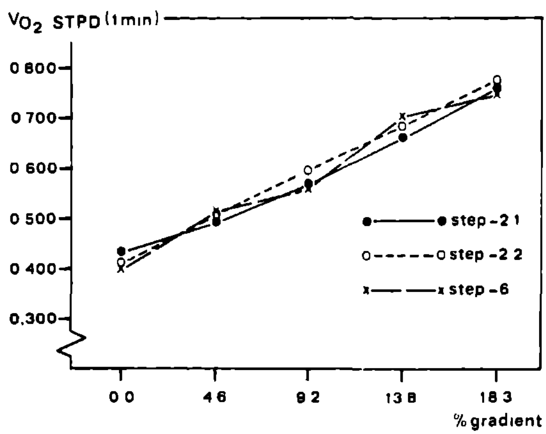


Figure 2. Heart rate and O_2 consumption in relation to % gradient for different treadmill tests.

The $\dot{V}_{O_2}$ max. was calculated from the linear regression equation with a fixed maximum H.R. of 210 beats.min^{-1} (see Figure 1). The maximal oxygen consumption was measured in the laboratory (approximately 4 to 6 months after the W170 was measured). Criteria for the determination of maximal oxygen consumption were a marked leveling of the H.R., gradual reduction in the capacity for running uphill, and, after analysis, a maximal respiratory exchange ratio (R) higher than 1.1.

RESULTS

In Figure 2, the H.R. and the $\dot{V}_{O_2}$ are plotted against the % gradient for the step-2.1, step-2.2 and step-6 tests. A linear increase in H.R. and $\dot{V}_{O_2}$ can be seen for an increase in workload in this group of 5-year-old children. There are no significant differences between the two trials of the step-2 test with respect to the H.R. (see Figure 3). The girls have a higher H.R. than the boys at all workloads. These differences are also shown in the results of the W170 (Table 1). The W170 scores for the boys are about 30 % higher than for the girls. The test-retest correlation

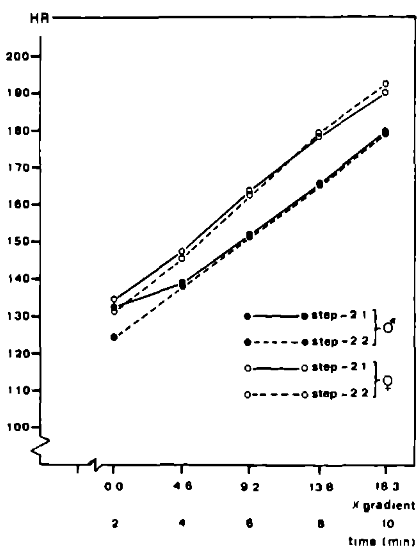


Figure 3. Heart rate of boys and girls in relation to % gradient for both 2 minutes increasing treadmill tests.

coefficients for the oxygen consumption were greater than r=0.9, except for the first workload. The H.R. scores varied somewhat more and had test-retest correlation coefficients ranging from 0.65 to 0.85. The results of the W170 agree with this finding (Table 1).

The results of the validation procedure are given in Table 2. The mean difference (± S.E.) between the calculated and measured values is +1.59 ± 0.78 $ml.kg^{-1}min^{-1}$. The mean measured maximal H.R. is lower than the "known" maximal H.R. used in the calculation of the $\dot{V}_{O_2}$ max. The correlation coefficient of the $\dot{V}_{O_2}$ max.-direct - W170 and $\dot{V}_{O_2}$ max.-direct - $\dot{V}_{O_2}$ max.-indirect is 0.73 and 0.57 respectively.

Finally, Table 3 shows the children divided into 3 subgroups according to their $\dot{V}_{O_2}$ max.-direct values: group 1, $\dot{V}_{O_2}$ max. <45 $ml.kg^{-1}min^{-1}$; group 2, $\dot{V}_{O_2}$ max. 45-60 $ml.kg^{-1}min^{-1}$; and group 3, $\dot{V}_{O_2}$ max. >60 $ml.kg^{-1}min^{-1}$. Comparing the mean scores of the $\dot{V}_{O_2}$ max.-indirect, W170 or the endurance time one notices that these indices for predicting the physical performance capacity show significant different values between the high and low $\dot{V}_{O_2}$ max.-direct groups.

DISCUSSION

The primary goal of this investigation was determine the extent to which the use of a submaximal treadmill test for young children yields results comparable to the generally used maximal oxygen consumption measurement. It can be concluded from the first series of experiments that no significant differences are found between the treadmill test in which the workload is increased every 2 minutes and the treadmill test in which the workload is increased every 6 minutes in relation to the H.R. and $\dot{V}_{O_2}$ scores. This is in agreement with Skinner et al. (1971), who found no significant differences between comparable treadmill tests for 6- to 15-year-old children. Mocellin et al. (1971) on the other hand, obtained H.R. scores for a continuous bicycle ergometer test which were lower than H.R. scores obtained from a step-wise increasing test for 11- to 13-year-old children. The difference in age may be an explanation for these findings.

Figure 2 shows that there is a linear relationship between H.R. and workload, except for the scores of the first workload. For this reason,

Table 1. Mean W170 (± S.D.) results from 2 trials of the step-2 test and test-retest correlation coefficients.

		W170 (% gradient)		
	n	test-2.1	test-2.2	test-retest coefficient
Boys	11	15.6 ± 4.1	15.3 ± 5.1	0.69
Girls	11	10.6 ± 3.3	10.9 ± 3.4	0.71

Table 2. Maximal oxygen consumption (direct and indirect method) and maximal heart rate in 41 8-year-old boys. Mean values and range.

		Maximal O_2 consumption		
Weight (kg)	Height (cm)	Direct ($ml.kg^{-1}min^{-1}$)	Indirect ($ml.kg^{-1}min^{-1}$)	Max. heart rate ($beats.min^{-1}$)
29.3	133.1	55.4	56.9	204.0
28.5-58.0	125-152	33.6-66.0	35.0-76.8	190-220

Table 3. Indices of physical performance ranked according to maximal O_2 consumption (direct).

$\dot{V}_{O_2}$ max. ($ml.kg^{-1}min^{-1}$)	<45	45-60	>60	p[a]
number	6	24	11	
$\dot{V}_{O_2}$ max.-direct	39.4	55.8	63.1	
$\dot{V}_{O_2}$ max.-indirect	42.2	54.9	67.4	<0.001
Endurance time (min) Bruce test	10.0	12.7	13.8	<0.001
W170 (% gradient)	8.2	15.1	17.5	<0.001

[a]Student's *t*-test between lowest and highest $\dot{V}_{O_2}$ max. groups.

the H.R. score of the first load was not included in the calculation of W170. Mocellin and Rutenfranz (1970) emphasized the importance of a good linearity of the H.R. during increasing workloads for calculating the W170. The average scores of the W170 calculated from the step-2.1 and step-2.2 are in good agreement. Individual differences are sometimes great, resulting in a correlation coefficient of about 0.7. Lindemann et al. (1973) found comparable scores using a bicycle ergometer test.

There are striking differences between the mean H.R. of boys and girls at the various workloads. Skinner et al. (1971) did not find these differences. Studies by Klimt and Haense (1970) and recently Lindemann et al. (1980) indeed show clear differences between 4- to 18-year-old boys and girls.

Comparing measured oxygen consumption for comparable workloads with values in the literature (Silverman and Anderson, 1972) reveals that the oxygen consumption is somewhat higher for our group. Margaria et al (1963) and Klimt and Voigt (1974) among others, have shown that walking or bicycling efficiency is a factor. The walking speed of 4 $km.hr^{-1}$ was perhaps a bit too high in this respect, although our impression was that the children had no trouble walking at this speed.

In the second series of experiments we investigated the extent to which an accurate prediction of the measured oxygen consumption can be made using the chosen test (step-2). The mean scores for the calculated $\dot{V}_{O_2}$ max. closely coincide with the measured values. It should be noted that the chosen max. H.R. of 210 $beats.min^{-1}$ is too high with respect to the measured H.R. max. (204 $beats.min^{-1}$). Although the mean scores are in good agreement, large individual differences can appear between indirect and direct $\dot{V}_{O_2}$ max. The correlation coefficient (r=0.73) is equal to or a bit lower than the known values found by bicycle ergometer tests with older children and adults (Mocellin et al., 1971: r=0.75 to 0.84; Woynarowska, 1980: r=0.52 and 0.82).

The relatively long period between the two tests is a possible explanation. On the other hand, the W170 scores were unchanged during the preceding 2 years for these selected children.

The correlation coefficient of indirect and direct $\dot{V}_{O_2}$ max. is higher than for the W170 method. Mocellin et al. (1971) found no difference between the correlation coefficient of the W170 and $\dot{V}_{O_2}$ max.-direct and that of

$\dot{V}_{O_2}$-indirect and $\dot{V}_{O_2}$ max.-direct. This discrepancy between our results and the results of Mocellin et al. (1971) can be explained by the fact that they calculated the indirect and direct scores from the same exercise test. Day by day fluctuations in H.R. as a result of such variables as temperature changes, are avoided this way. The intra-individual differences in the $\dot{V}_{O_2}$ max.-indirect are of less importance when groups are compared. It can be concluded from Table 3 that depending on the available time, equipment and manpower any of the given indices may be selected for recording physical performance capacity as long as group means are being compared.

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Chapter 3.1.

THE USE OF PEDOMETER AND ACTOMETER IN STUDYING DAILY PHYSICAL ACTIVITY IN MAN
PART I: RELIABILITY OF PEDOMETER AND ACTOMETER

W.H.M.Saris and R.A.Binkhorst
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SUMMARY

The purpose of this study was a critical evaluation of pedometer and actometer for estimating daily physical activity.

Both instruments were tested for reliability on a carriage with movements in different directions. To obtain comparable data of different pedometers it was necessary to adjust the spring tension very carefully. The reliability of the individual actometer was satisfactory, but there were large differences between the watches. Therefore, a correction factor (C.F.) was introduced.

Some experiments were carried out on a treadmill. 9 Children (aged 5-6 years) and 6 young adult males (aged 21-31 years) walked and ran at different speeds. The energy expenditure was calculated from formulas. The pedometer overestimates the actual step rate with 0.1-0.3 counts per step during fast walking (6-9 km.hr $^{-1}$) and fast running (15 km.hr $^{-1}$). It underestimates the actual step rate with 0.2-0.7 counts per step, while walking slowly. It was shown that the pedometer does not reflect the differences in energy expenditure levels at different speed very well. The actometer units per step increases more or less proportional to the speed of walking and running. In contrast to the pedometer results the actometer results are more related to the energy expenditure levels at different speed.

The results of this study suggest that the actometer might be a valid indicator of the daily physical activity in terms of energy expenditure.

Key words: Pedometer - Actometer - Daily physical activity - Energy expenditure - Treadmill.

INTRODUCTION

It is very likely that the lack of daily physical activity in modern society has become an important factor in the etiology of certain health problems, such as coronary heart disease and obesity. Thus, in the study of the relationship between these factors it is necessary to determine the intensity and the amount of the daily activities.

According to Edholm (1966) the methods to establish these can be divided into two categories. First are the measurement methods, by which, the physiological response to activity, i.e. oxygen consumption, heart rate, etc., is obtained. Secondly the observation methods by which the physiological response is estimated, via direct or indirect recording of movements, like time- and motion studies, motion picture sampling, questionnaires and the diary method. One of the criticism of these techniques is that they interfere with the normal daily live of the subjects and the experiments are often restricted to only a part of the total daily activities of the subjects. In the category of observation methods, many ingenious devices besides those mentioned above have been used to try to obtain an objective estimation of the movement of the body over a longer period of time and with reasonable accuracy with a minimum of disturbance to the normal life pattern. Two of those methods will be described more extensively.

In 1926 Lauter was the first to describe an investigation with the use of the pedometer. In 1959 Schulman and Reisman reported on the actometer as a device which they used especially for the measurement of hyperactivity.

In the literature there is little information about the accuracy of both instruments. The purpose of this study was to evaluate critically the usefulness of the pedometer and actometer.

METHODS

A. Instruments, System Description

1. Pedometer

The pedometer records the acceleration and deceleration of movements in one direction. The function principle is that an arm balanced by a delicate spring is displaced downwards by slight jolts in the direction of suspension.

This movement turns a number of gears and finally a hand. There are two mechanical systems of counting in the commercially available pedometers. The first one is described by Stunkard (1960). In this system the displacement of the balance arm and consequently of the hand can be calibrated with the length of the stride of the subject. This means that the impulse of each step is converted into distance. On the face one can count the total distance walked in a certain period of time. However, all other movements of the body which produce an impulse great enough to displace the balance arm turn the hand one stride length. Thus, as a result of the calibration, all other movements will also be expressed in terms of the stride length of the subject. If the pedometer is worn by someone with a small stride length there will consequently be an underestimation of all other movements in comparison with someone with a greater stride length. Since all movements are part of the daily activity of the subject, it would be better to count all movements in the same way, instead of using a precise measurement of the distance walked. Then it is possible to compare the data of different subjects with greater reliability. Usually this type of pedometer is only available with a breakable plastic case. Furthermore, it is not possible to regulate the spring tension of the balance arm with sufficient accuracy.

We would prefer not to use this type of pedometer for studying physical activity.

The second pedometer counting system is the registration of any impulse that can move the balance arm downwards. The instruments with this system have cases like that of a normal stopwatch and the spring tension can be regulated accurately. Counting is possible up to 10^5 impulses. There are two types; the Russian and the German. Since the Russian type seemed to be more durable, we chose this one for further research.

A completely different form of pedometer is the battery powered electromagnetic stepcounter described in detail by Marsden and Montgomery (1972). We did not use this type because this pedometer still poses certain problems (Staveren, 1974) and is less suitable for children. The best place to wear the pedometer is the waist. The jolts are too strong at the ankle, and causes the pedometer to count irregularly (see Results, Table 2). It is necessary to fix the pedometer securely to the waistline. When it is suspended loosely from the waist, more movements are counted than the body makes and, consequently, this will result in an overestimation of the amount of activity.

2. Actometer

The actometer is an automatically winding calendar wrist watch from which the escape mechanism has been removed. The rotor is thus directly connected to the hand. The results can be read in days and hours (actometer units). The instrument records acceleration and decelerations with a component in the same plane as the face of the watch. In effect, it records not only the movement but also its intensity; i.e. the rotor turns more times as the intensity of the movement increases. Its size and shape makes it easy to wear without interfering with the daily habits of the subject at all.

In order to determine the most suitable position to wear the actometer it was fixed to several sites of the subject's body. Since it was very difficult to fix it properly to the waist, we prefered fixation to the extremities.

B. Testing Reliability

In order to test the reliability of both instruments (Russian pedometer and actometer), they were mounted on a carriage connected by a drive shaft (length 14 cm) with a crank (length 15 mm) rotating at different speeds (compare with piston engine).

For the pedometers the movement was in the direction of suspension. The actometers were tested on a rotating plate. These modified watches (Tussot, Swiss made) were mounted with the face parallel to the plane of rotation. Because acceleration and deceleration of movements are an important part of the daily physical activity it was decided to test also other standardised movements. The same apparatus as described above was used but this time the carriage was moving horizontally to and fro.

In order to simulate normal activities like walking and running some experiments were carried out on a motor-driven treadmill in the laboratory. All external conditions like temperature, remained constant. The participants were 6 young adult males (range 21-31 years) and 9 children (range 5-6 years). The subjects were familiar with walking and running on the treadmill. They wore carefully calibrated pedometers on the waist (left and right) and a third one on the left ankle.

The actometers were fixed to the right ankle and right wrist. The adults walked and ran at different speeds for 10 min. Above the speed of 10 $km.hr^{-1}$ they ran 5 min. The children walked 10 min and ran 5 min. The experiments with the whole range of speeds were repeated on another day. During the experiment the stride frequency was counted. The length of stride was calculated from the speed and stride frequency (Högberg, 1952). For the adult participants, the energy expenditure was calculated from the formula

Walking: $E(kcal.10^{-3}.kg^{-1}min^{-1}) = 21 + 0.0070\ V^2\ (V = m.min^{-1})$

Running: $E(kcal.10^{-3}.kg^{-1}min^{-1}) = 17.913\ S - 19.55\ (S = km.hr^{-1})$

(for references see Hermans-Teluy et al., 1974). This formula is similar to other formulas found in the literature. For the children, the regression equations given by Silverman et al. (1972) were used.

Walking: $\log 10\ \dot{V}_{O_2}/kg = (0.0969 \times V) + (0.021 \times \%) + 0.751$

Running: $\log 10\ \dot{V}_{O_2}/kg = (0.0367 \times V) + (0.0102 \times \%) + 1.238$

$V = km.hr^{-1}$ $\% =$ gradient

RESULTS

1. Calibration

From the experiments with the carriage it appeared that the degree of reliability, obtained with one pedometer depends only on the spring tension of the balance arm. Below a certain critical rotation speed the pedometer does not count. Above this point, each impulse will be counted correctly. There is, however, a great difference in the rotation speed of the carriage at which the different pedometers start to count (range 116-150 $rot.min^{-1}$, n=10). Thus to obtain comparable data it was necessary to adjust the spring tension in such way that all pedometers started counting at the same impulse level. After setting all to one critical counting level, the range of rotations at which they started counting was drastically reduced (range 107-111 $rot.min^{-1}$, n=10). In repeated experiments the same pedometer always started counting at the same rotation speed.

The actometers were tested for reliability by rotating on a plate with a constant speed, like Schulman et al. (1959) and others (Macke, 1974; Rose et al., 1968) did. The degree of reliability obtained with the same watch was extremely high, while the differences between watches were very small. We obtained the same results (see Table 1 left side) with ten modified watches. With a two factor analysis of variance it turns out that there are no significant differences between the five experiments (row-F ratio) and between the ten different watches (column-F ratio). This can be explained easily. Since there is no acceleration and deceleration in a constant rotatory movement, the turning of the rotor of the actometer is synchronized with the rotation of the testing machine. The results of the calibration with the horizontal to and fro movement are also tabulated in Table 1 (right side). The reliability of each watch was satisfactory except for watch No. 6. But there were large significant differences between the watches. These results also appeared with other standard movements like rotation with acceleration and deceleration movements, moving to and fro at an angle of 45 degrees. In practice, when different subjects wear different actometers a comparison of the results can be made by introducing a correction factor (C.F.). For each watch a correction ratio is calculated between the mean results of an arbitrarily chosen watch (No. 4) and the result of the watch in question (see Table 1 right side).

2. Walking and Running Experiment

The results of the treadmill experiments are tabulated in Table 2 and the Figures 1-4.

Table 2 contains averages and variances of the results of the pedometer and actometer readings and of the stride frequency, at different speeds. There were no differences in pedometer readings when the pedometer was worn at the left or right side of the waist. It was decided to use the results of the right pedometer in all subsequent analyses.

When the pedometer is worn at the waist it can be seen that it counts the number of strides more accurate than when it is worn on the ankle, especially during running. It is our impression that this is due to the very strong movements of the ankle. It can be seen that the impulses during walking 1 $km.hr^{-1}$ are too small to count each step. During fast walking the pedometer exaggerates the number of steps. To have a clear view on this phenomenon, the average pedometer readings per actual stride was plotted for all speeds (Fig. 1).

Theoretically these readings should be one pedometer unit per stride at

Table 1. The results of ten actometers (units) during rotation at constant speed and moving to and fro (number of experiments; 5, C.F.= correction factor, see text) and the results of the analysis of variance per actometer (rows) and for ten actometers (columns).

Actometer No.	Rotation (5 hrs.)		Horizontal to and fro (5 hrs.)		
	Mean	S.D.	Mean	S.D.	C.F.
1	57.9	0.08	502.0	18.0	1.29
2	57.9	0.05	641.4	19.1	1.01
3	58.0	0.06	763.6	10.9	0.85
4	57.9	0.03	646.6	9.8	1.00
5	57.9	0.07	700.3	8.7	0.92
6	57.9	0.04	501.0	136.7	1.29
7	58.0	0.04	649.4	15.7	0.99
8	57.8	0.08	645.2	11.9	1.00
9	58.0	0.09	396.6	18.4	1.63
10	57.9	0.04	693.6	17.1	0.93
Column F. 95	0.53 n.s.		22.51 sign.		
Row F. 95	1.81 n.s.		1.93 n.s.		

Table 2. The pedometer and actometer results per minute during walking and running of the subjects. (Total number of experiments, children=18, adults=15.)

	$km.hr^{-1}$	Pedometer (units min^{-1})				Actometer (units min^{-1})				Stride $freq.min^{-1}$	
		Ankle left		Waist right		Ankle right		Wrist right			
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Walking											
Children	1.0	56	7.1	34	21.5	0.97	0.5	0.6	0.5	107	13.2
	3.2	167	27.7	173	19.8	3.0	0.7	1.5	1.2	142	10.3
	5.1	217	48.9	205	15.1	8.1	2.9	4.5	3.6	163	14.7
Adults	5.8	125	19.2	121	12.2	4.0	0.6	0.6	0.4	118	3.1
	7.2	137	12.4	144	16.8	5.4	0.5	2.9	1.8	130	3.1
	8.6	206	18.8	183	39.1	7.7	1.9	4.9	1.6	146	4.4
Running											
Children	5.1	259	4.2	219	18.1	13.7	3.9	8.7	1.0	203	9.7
	6.5	250	3.9	225	10.3	15.7	3.8	10.9	2.5	212	14.0
Adults	7.2	213	13.5	155	8.8	12.2	1.5	8.2	0.6	152	10.7
	8.6	202	24.0	155	4.2	12.8	1.3	7.9	0.6	157	4.4
	10.1	169	45.1	163	5.2	13.9	1.0	8.3	0.6	158	5.0
	13.3	212	85.0	170	6.5	17.0	2.4	9.1	0.7	168	6.8
	14.8	76	27.5	192	12.4	20.4	3.2	7.4	0.9	176	2.6

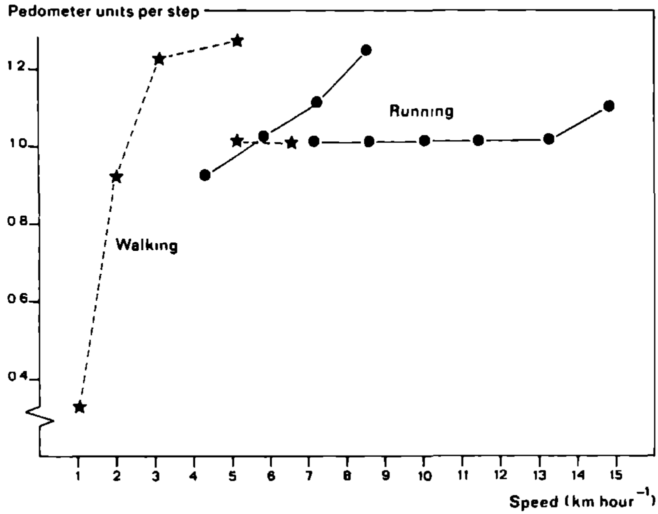

Figure 1.

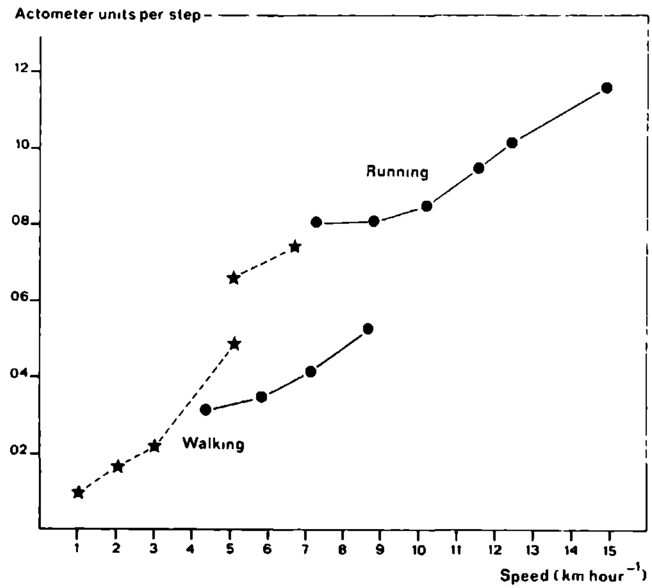

Figure 2.

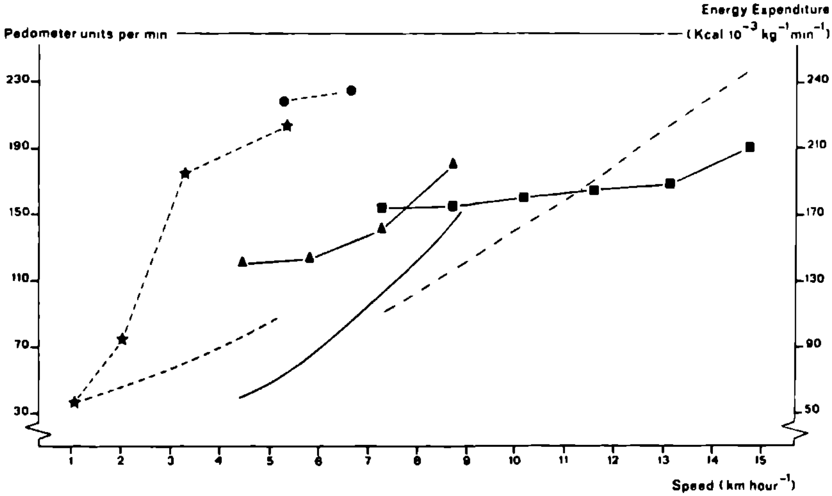

Figure 3.

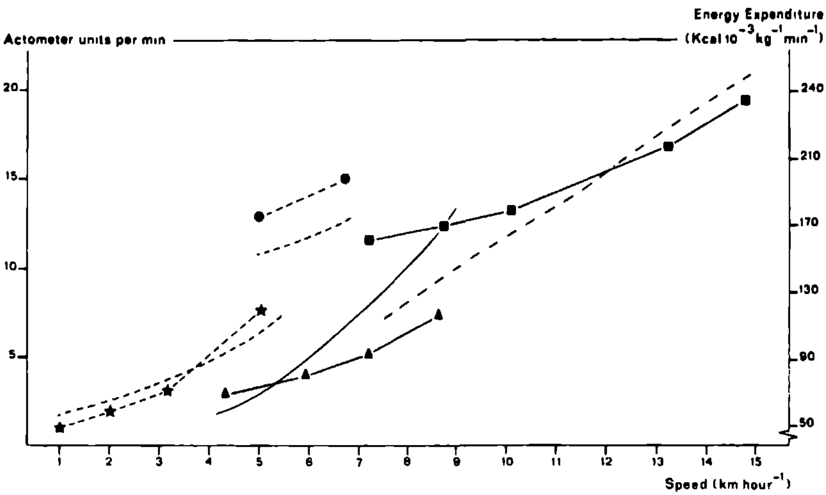

Figure 4.

Figure 1. The pedometer results (waist) per actual stride for walking and running at different speeds. Mean values for 9 children (✱) and 6 adults (●).

Figure 2. The actometer results (ankle) per actual stride for walking and running at different speeds. Mean values for 9 children (✱) and 6 adults (●).

Figure 3. The pedometer results (waist) - mean values for 9 children: walking (✱) and running (●) and 6 adults: walking (▲) and running (■) - plotted against the energy expenditure - children: walking (---) and running (....), after Silverman et al. (1972), adults: walking (——) and running (—·—·—), after Hermans-Teluy et al. (1974).

Figure 4. The actometer results (ankle) - mean values for 9 children: walking (✱) and running (●) and 6 adults: walking (▲) and running (■) - plotted against the energy expenditure - children: walking (---) and running (....) after Silverman et al. (1972), adults: walking (——) and running (—·—·—), after Hermans-Teluy et al. (1974)

different speeds. It is shown that the results range from 0.3-1.3 units per stride for walking at different speeds. During running it is shown (Table 2) that the pedometer follows the stride frequency. Table 2 shows also that in most cases the variance of the pedometer results is of the same order as that of the stride frequency. Only when the pedometer is worn on the ankle does the variance increase.

Figure 3 is a plot of the mean pedometer results and the calculated energy expenditure at different speeds. During walking, the pedometer counts increase from 3 $km.hr^{-1}$ proportionally with the energy expenditure. As described before, during running the pedometer counts are relatively constant while the energy expenditure is steadily increasing with higher running speeds.

Table 2 summarizes also the mean and variance of the results with the actometer fixed to the ankle and wrist. The score of the ankle actometer increases somewhat proportionally with the speed. This is also shown in Figure 2, where the mean ankle actometer readings per step are plotted against the walking and running speeds. With respect to the pedometer readings in Figure 1, it can be seen that, especially during running the actometer readings are quite different; there is an increasing number of actometer units per step with increasing speed, this accentuates the fact that the actometer also reacts on the intensity of the movement. In this case, the subject meets the ground with a greater impulse, due to the greater stride length, which causes a higher acceleration and deceleration to the actometer. Figure 4 shows the ankle actometer readings and the calculated energy expenditure at different speeds: As can be seen they have the same tendency. During walking and running from 1 $km.hr^{-1}$ to 15 $km.hr^{-1}$ the actometer readings increase proportionally with the energy expenditure. The data of the actometer at the wrist, listed in Table 2, are relatively constant for the different running speeds. Therefore, the results of the actometer at the wrist are comparable with the pedometer findings.

DISCUSSION

Already in 1947 Reed observed in his review that a clarification of the methods of measuring physical activity was needed.

In the literature about the pedometer and actometer (Johnson, 1971; Lauter, 1926; Massey et al., 1971; Rose et al., 1968; Schulman et al., 1959), stress is put on the fact that both instruments measure the activity of the body by registrating the impulse of movements and converting these into length units. The pedometer results are often given in miles per day. The same approach is applied in the use of the actometer by Johnson (1971) who compared the results of different tests movements (rotation, to and fro) of the actometer on base of actometer units per inch. From these experiments, he concluded that it will be difficult to relate data collected with the actometer to the actual physical activity.

In both instruments, however, registration is based on acceleration and deceleration. Therefore, evaluation of the data in terms of distance, as done by Johnson, will not reveal the usefulness of both instruments. The pedometer registrates each time a certain level of acceleration or deceleration is reached in the direction of suspension. In this respect it can be said, on basis of our results, that the Russian pedometer is a reliable recorder. Only if the movement is very strong, i.e. fast walking and running there is a tendency to overestimate the actual step-rate (which is about 20 %). The actometer registrates the acceleration and deceleration of the movements with components in horizontal and vertical direction in the same plane as that of the watch. When the actometer is tested with calibration movements it is seen that there is an inter- and intra-instrumental variation. The intra-instrumental variation is acceptable. Since the inter-instrumental variation is too great a correction factor (C.F. in Table 1) is needed to make the results of different actometers more comparable. Massey et al. (1971) used a specially produced serie modified watches and "equalized" them also by means of a correction factor. However, no data of the reliability are reported.

If the aim of the application of both apparatus is to study the physical activity in terms of energy expenditure, then another problem is the correlation between the pedometer and actometer results and the energy expenditure. We have tested these relationships with subjects who were walking or running and used formulas to predict their energy expenditure. The results illustrate that the counts of the actometer fixed at the ankle have a closer relation with the energy expenditure than that of the pedometer fixed to the waist; especially during running where the pedometer readings

remain almost constant with increasing speed (Fig. 3). These findings support the view that the actometer fixed to the ankle gives more valid information about the energy expenditure than the pedometer fixed to the waist.
In general it is concluded that both instruments accurately registrate certain types of movements of the body.
To evaluate human physical activity in terms of energy expenditure, we prefer to use the actometer.

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Chapter 3.2.

THE USE OF PEDOMETER AND ACTOMETER IN STUDYING DAILY PHYSICAL ACTIVITY IN MAN
PART II: VALIDITY OF PEDOMETER AND ACTOMETER MEASURING THE DAILY PHYSICAL ACTIVITY

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SUMMARY

The validity of the pedometer and actometer for estimating the daily physical activity was evaluated by means of an observation study. The physical activity in a classroom of 11 pupils of a kindergarten was assessed by means of a pedometer, actometer and by observation. Besides this an activity questionnaire was completed by the infant-guide. On basis of the individual observation it is clear that the infant-guide can give valuable information about the activity of the children at school.

The results of the pedometer attached to the waist and the actometers attached to the ankle were significantly correlated with the results of the observation method. The wrist actometer showed a smaller but still significant correlation with the other variables. Implications of this findings are discussed in regard toward the physical activity. The pedometer results point out that when the percentage of intense activity is high the pedometer tends to underestimate the level of activity.

The actometer results indicate that such a motion recorder gives a reliable estimation of activity in children. The findings are discussed in terms of the practical applications of the actometer in the research of daily physical activity and the physical rehabilitation treatment of certain diseases.

Key words: Pedometer - Actometer - Daily physical activity - Observation - Children.

INTRODUCTION

It is well known that daily physical activity varies enormously. To obtain a reliable impression of this activity, it is necessary to measure for a period of several days. With the usual methods it is impossible to gather reliable data over daily physical activities. This is especially true in studies of children.

The pedometer and particularly the actometer seemed to be a solution for this problem. The advantages, restrictions and reliability of these two instruments are described in a previous paper (Saris et al., 1977). As far as we know there is no information available about the validity of both instruments in measuring the daily physical activity. To clarify this, an observation study of the physical activity of a group of children was undertaken in combination with a questionnaire and the application of the pedometer and actometer.

METHODS

The present study was carried out in a kindergarten in an urban area. The age of the children visiting this type of school is 4-6 years. Each class has 20-30 children. The schooltimes are from 9.00-12.00 hrs. and from 13.30-15.30 hrs. The individual playing activity is a very important part of the school program and therefore an ideal situation for measuring different forms of physical activity. The purpose of the study was explained to the infant-guides.

Questionnaire

Data on the physical activity of the children were collected by means of an activity questionnaire completed by the infant-guides. This questionnaire is a list of some carefully selected items about the childs behaviour in every day school situations such as playing, paying attention etc. The questions were of the five-point scale type. The questions were arranged in such a way that high scores correlated with a high degree of activity. An evaluation regarding reliability and validity was made in an intensive pilot study (Saris et al., 1975). The boys and girls (n=11, age 4.8-6.1 years) with the highest and lowest scores were selected for the following experiment.

Pedometer and Actometer

Each day ten children were given a pedometer at the beginning of the schoolday. Each pedometer was enclosed in a sealed pocket (Kemper et al., 1974) which was fixed to the childs waist at the right side.

The two children with the highest and the two with the lowest questionnaire scores were given two actometers in addition to the pedometer. These were fixed to the ankle and wrist at the right side. The faces of the watches were covered with tape so that the children could not see the movement of the hands. At the end of the schoolmorning, the devices were taken off and the results were recorded. In order to avoid effects of inter-device differences, the same combination of actometers and pedometers was used in each experiment.

Observation

During the schoolhours, the children were observed in the classroom by someone who was familiar with the children. Each child was observed at two minutes intervals and the type of activity at the moment of observation was recorded (Tippett, 1935). The observation was differentiated in one of four categories (sitting, standing, walking and running), and at one of two levels of intensity (high and low).

To evaluate the results, a score factor was introduced based on the energy expenditure tables from Bink et al. (1969). The activity of sitting quietly with an energy expenditure of 14 kcal $10^{-3}kg^{-1}m^{-1}$ was given arbitrary the value of "one". The energy expenditure values of the other activities were related to that of sitting quietly to obtain a factor for each activity. Summation of the different indices gives the observation index for a given period. This is illustrated in Table 1.

The purpose of this observation index is only to get an impression of the total activity of each subject over a period of time. All the readings were obtained from 9.00-12.00 hour during one week from Monday until Friday.

RESULTS

Table 1. The calculation of an observation score (example) based on the energy expenditure tables after Bink et al. (1966).

Posture	Intensity of movement	kcal 10^{-3} kg^{-1} min^{-1}	Multipl. factor	Example	
				Times obs.	Index act.
Sitting	low	14	1	25	25
	high	28	2	4	8
Standing	low	18	1.3	21	27.3
	high	34	2.4	1	2.4
Walking	low	50	3.6	10	36.0
	high	75	5.4	0	0
Running	low	80	5.7	8	45.6
	high	150	10.7	0	0
				Obs. Index	144.3

The results of the investigation are presented in Tables 2 and 3, Table 3 shows the correlations between the variables tabulated in Table 2. Three actometer scores were used for the correlation matrix: the actometer readings taken from 1. the ankle, 2. the wrist and 3. the sum of 1 and 2 (actometer total). There is a highly significant correlation between the data collected from the observation, the pedometer and actometer ankle readings and the actometer total. Only the wrist actometer has a smaller but still significant correlation with the other variables. There is a strong agreement between the impression of the infant-guide and the more objective measurements (see Table 2). Between the most and least active children there is a significant difference for all the measured parameters. There is no significant difference as measured by the observation index between these two groups. In this case the pedometer gives a small but significant difference. There are no actometer results in these groups. The activity level of an individual child varies considerable during one week. This is illustrated in Figure 1 for the most active and inactive boy, (No's 1 and 4 respectively) and girl (No's 5 and 3 respectively); the individual results obtained with the different methods are plotted for the different days.

DISCUSSION

In order to acquire further information about the usefulness of pedometer and actometer, its validity was determined by measuring daily school activities with these instruments at one side, and the response to a questionnaire and a observation study in a kindergarten classroom during one week, at the other side.

Several investigators have noted the value of the observation method for recording physical activity (Wolff, 1959). In the present study a high correlation is found between data obtained with this method and the data obtained with both instruments. These findings suggest that the actometer and pedometer both registrate physical activity.

The pedometer, yielded a surprisingly high correlation with the other methods, particularly since it was shown that the pedometer underestimates physical activity of high intensity (Saris et al., 1977). From the obser-

Table 2. Mean, standard deviation (S.D.) and levels of significance of activity indices of groups of children formed by the infant-guide on base of her impression of the activity.

Group	No. children	No. exp.[b]	Observation index		Pedometer (units)		Actometer (units)			
					Waist		Ankle		Wrist	
			Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Most active	2	10	148	33	2530	731	204	72	170	48
Least active	2	10	108	29	1346	911	140	70	148	49
Difference[a]				++		+++		+++		+
Active	4	18	137	39	2390	1385		–		–
Less active	3	12	129	35	1561	1410		–		–
Difference[a]				n.s.		+				

[a]Student's t-test, p=0.001 +++; p=0.01 ++; p=0.05 +; n.s.=not significant.

[b]Number of days measured from 9.00-12.00 hour in this schoolclass.

Table 3. Correlations between the different methods to determine daily activity.

Methods	a	b	c	d	e
a. Pedometer waist	–				
b. Actometer ankle	0.89[b]	–			
c. Actometer wrist	0.78[a]	0.69	–		
d. Actometer total	0.95[b]	0.96[b]	0.86[a]	–	
e. Obs. index	0.93[b]	0.97[b]	0.71[a]	0.97[b]	–

[a]Significant at a 5 % level.

[b]Significant at a 1 % level.

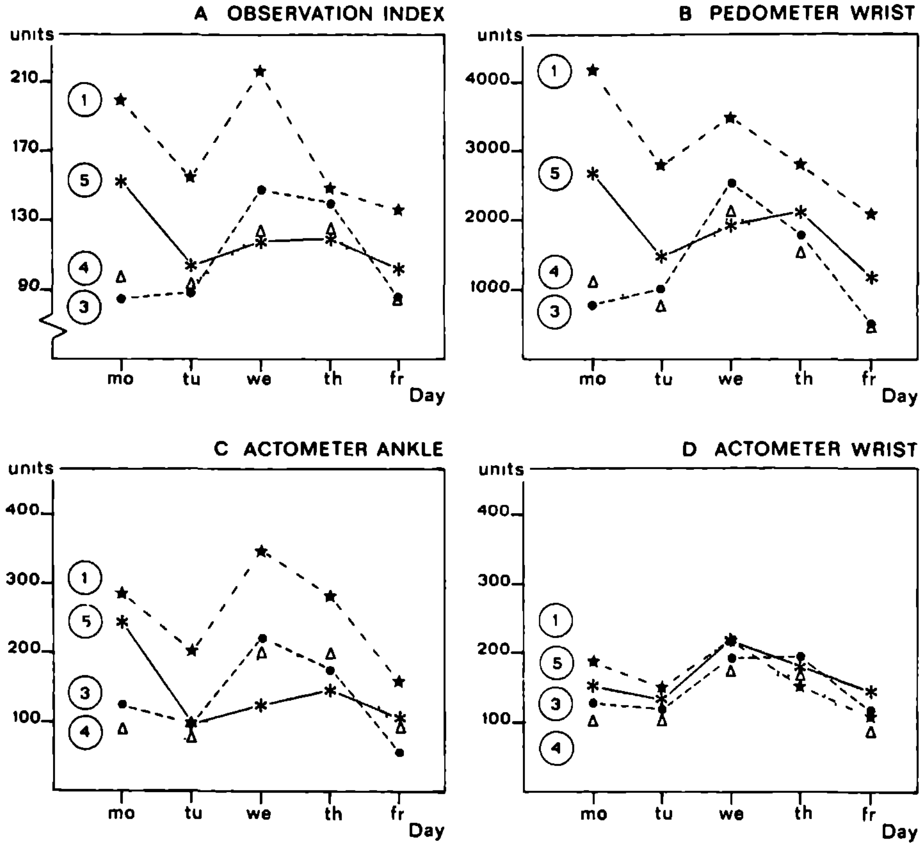

Figure 1. The activity levels for the different methods of the most active and inactive boys and girls (see text) during five subsequent days (4 = child number).

vation results in this study it could be seen that the number of times that running was observed varied from 0-14 % of the total observations. When this percentage was high, it was noticed that the pedometer gave a lower reading. For example, on Wednesday child No 1 (see Fig. 1) ran frequently. He had a running percentage of 13.2. However, the pedometer reading was low. This confirms our previous findings (Saris et al., 1977) in which it was shown that the pedometer does not count higher levels of activity, as it does at lower levels. It is obvious that there is limited opportunity for running in a classroom. Perhaps this factor hides the limitation of the pedometer in this study. The actometer on the wrist shows a smaller correlation with the other variables. If the actometer on the ankle correlates well with the other variables and the actometer on the wrist not, this might suggest that the arm movements gives less addition information about the activity.

It is also possible that general observation methods pay more attention to movements of the leg than to the movements of the arm. This needs further study with the aid of more sensitive methods like the picture sampling technique.

It is quite clear that actometers on the ankle and wrist reflect different levels of activity. Because we did not have reliable data about the energy expenditure of arm and leg movement we decided to add up both variables (actometer total, Table 3). The results from the actometer fixed at the wrist as illustrated in Figure 1 show little differences among the four children. This suggests that differences in physical activity are due mainly to the differences occuring in the levels of activity in the lower extremities, i.e. walking and running.

The third instrument used in this study was a short questionnaire given to the infant-guide. The results in Table 2 indicate that there is a good correlation with the objective methods. This findings supports the view, that the infant-guide is able to recognize the most active and inactive children in the group.

When reviewing these results three important conclusions become apparent. First, the actometer is useful in studying physical activity over a period of several days as was found in a limited study on two very active and two inactive children. This needs further research. It is a light and relatively inexpensive device and therefore allows the experimentator to study large groups over long periods of time. This is not possible with the accurate but more expensive instruments like the heartbeat recorder. We suggest that a combination of both methods may result in an improvement of the evaluation. Another important application of the actometer might be its use in physical rehabilitation of hometreated cardiac patients, hyperactivity or rheumatism. Where it might add to a more objective evaluation of the results of the treatment programs. The second conclusion concerns the pedometer, it is also cheap and light weighed but it has more limitations in recording the intensity of an activity. The present study points out that when intensity is low, the pedometer records correctly. When it is high the pedometer tends to underestimate the level of activity.

Thirdly, the study indicates that the infant-guide can give valuable information about the physical activity of the children at school.

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Chapter 3.3.

RECENT DEVELOPMENTS IN MOVEMENT COUNTERS

Since our publications about the pedometer and actometer (Chapter 3-1, and 3-2), as simple devices for recording daily activity, a number of publications have appeared showing the possibility that the method will play a meaningful role in the near future in research on daily physical activity. For this reason, a short summary of these papers is given here.

A change was made in the pedometer by Verschuur and Kemper (1980). They adjusted the spring tension so that the meter worked only during running exercises. This modification was meant to measure high intensity activities. They pointed out that these forms of activity can have a training effect on the aerobic power. The pedometer results of an investigation with boys and girls, 13-14 years of age, agreed with those of an activity questionnaire (Kemper, 1980). Groenewegen published his doctoral thesis in 1979 entitled "Adipositas, bewegingspatroon en calorie-opname" in which the physical activity of obese and non-obese children were compared using the actometer. To get an impression of the validity of the actometer, bicycle tests were performed as well as a number of treadmill tests, such as in our study (Chapter 3-1). The actometer was worn just above the knee, contrary to our measurements in which the actometer was attached just above the ankle. The results for walking and running were in agreement with our observations (Figure 3 and 4, Chapter 3-1). In contrast to our experience with the actometer fastened to the ankle (unpublished results) the actometer above the knee registered well for bicycling. It is possible that placement above the knee is better for recording physical activity. This presents more problems, however, for fastening the actometer securely.

Concurrent with our study, Mc Partland et al. (1976) published results for a movement counter based on a miniature mercury switch. The equipment is 38x4.5x2.2 cm and weighs 51 gr. Good agreement was found between the results obtained by this equipment and an activity questionnaire (Mc Partland et al., 1975).

Finally, in recent years, partly due to the spectacular advancements in microelectronics, a development has started, to design an electronic alternative analogous to the measurement principle of the actometer (i.e. measuring the intensity of the movement). Although the actometer gave reasonable results for the estimation of the physical activity we did not use this modified wrist watch in our further studies with children because of mechanical problems during lengthy experiments. Therefore, a team from the Technical High School in Twente (The Netherlands) began work on such an electronic design in co-operation with our department. This is based on a piezo electric ceramic (pick-up) element with a seismic mass (v. Dijk, 1979). The first results are encouraging. In the meantime, inexpensive micro-accelerometers (Lauer, 1977) which are suitable for such a design have been developed by industry.

Finally, the interest in movement counters is not only present in human research. Also within the dairy industry movement counters are being developed for detecting the estrus period in cows. Movement during this period is about 2 to 4 times higher than normal (Marshall, 1980). It can be expected that through these developments within a few years electronic counters based on the measurement principle of the actometer will be available. Furthermore, the development of low-cost microprocessors will make it possible to collect information for each time unit over longer periods of time (1 week or longer) at different grades of intensity.

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Chapter 4.1.

A PORTABLE HEART RATE DISTRIBUTION RECORDER FOR STUDYING DAILY PHYSICAL ACTIVITY

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(published in Europ.J.appl.Physiol.37, 17-25, 1977)

SUMMARY

This paper provides a brief description of a new 8-register heartbeat integrator for recording the heart rate over a long period (24 hrs. or more) in order to assess daily physical activity in children and adults.

This compact, solid device records the cardiac beat to beat interval in seven registers, ranging from 40-225 beats.min^{-1}. An eight register, the so called "quality level"; (range 225-300 beats.min^{-1}) is added to count all non-physiological pulses resulting from muscle noise, etc. To test for validity this system was evaluated simultaneously against two established systems; a manual acoustic monitoring system and a heart rate recording system. Comparison of the results demonstrated good agreement. Integrator influences on the normal daily activity behaviour of the children (age 5 yrs.) was checked with the pedometer method. It was found that wearing of the heartbeat integrator did not appreciably influenced the normal behaviour of the children.

Key words: Heartbeat integrator - Heart rate recording over 24-hrs. - Daily physical activity - Energy expenditure - Pedometer.

INTRODUCTION

It is now well established that monitoring the heart rate for a prolonged period (24 hrs.) can give valuable information about the daily physical activity of man (Edholm, 1966). Ideally the study of heart rate response on physical activity requires its continuous registration on a timebase. The telemetry system has the capability of measuring the heart rate response in this way (Geeseman et al., 1971; Klimt, 1974). Measuring heart rate over a long period such as a whole day however, would be very difficult with this system since the receiver must remain somewhere in the vincinity of the subjects. Another approach used is to record the impulses on magnetic tape (Seliger et al., 1970). However, the size and weight of the recorder may become a source of embarrassment to the subject, especially children. An alternative type of heart rate storage is the cumulative recording of the beats by a counter. This can be done mechanically (Rowley et al., 1959) or electronically (Baker et al., 1967). More recently, a counter was developed in which three ranges of the beat-to-beat interval can be stored (Sami, TEM Instruments, London, England). The disadvantage of the mono- or three-range counting system is that short bursts of activity with a high heart rate may pass unobserved. Therefore sub-dividing the heart rate measurement scale into more intervals may possibly give more information about the different levels of activity. Another problem of this type of integrator is the difficulty of detecting erroneous measurements of the heart rate.

After careful evaluation of different methods and equipment we decided to develop a new heart rate integrator which would meet the following criteria:

Beat-to-beat determination of heart rates from 35-225 beats.min^{-1}.

Fail safe triggering in the presence of motion artifacts, muscle noise and respiratory QRS amplitude fluctuations.

Quality control of the measurements by storage of the erroneous pulses.

A simple, quick and error free read-out procedure.

Size and weight must be small enough to allow little children (3-4 yrs.) to move freely during all their activities.

According to these criteria a new system was developed and evaluated.

MATERIALS AND METHODS

The system consists of three main units A. electrodes, B. heartbeat integrator, C. read-out machine.

A. Electrodes

Perhaps the most important unit for a successful completion of an experiment is a very careful fixation of the electrodes on the body (Hanisch et al., 1971). We preferred a two electrode system instead of a three electrode, in order to reduce the chance of nonvaluable measurements due to bad electrode contact and to save preparation time. We used a small mass electrode. The silver foil was embedded in a plastic holder (Ø=15 mm) that maintained a distance of 1.5 mm between the skin and silver foil (developed by A.C.A.Vissers, Dept. of Physiology, Univ. of Nijmegen). Conductive contact between skin and silver foil was made by electrode jelly. Electrode placement was made with the use of an electrode test-set (TEM Instruments, London, England): for reliable ECG transmission the minimum amplitude of the R-wave should be 1 mV. The most common place was to attach the electrodes to the manubrium sternum and to the apex at 5th rib. After the electrode sites were chosen, the skin was carefully swabbed with alcohol and abrade to give a low resistance (< 10 kΩ). The electrodes were attached with a polystyrene glue and controlled for sensitivity and resistance. The testing of the "electrode-subject" resistance is mandatory because this is the controlling factor in obtaining a stable signal.

B. The Heartbeat Integrator (Circuit Design)

The complete system is enclosed in a stainless steel box 63x94x22 mm in size and 220 g in weight. Children carry the box in a side pocket attached to a belt around the waist. Each R-R interval is detected, analyzed, recorded and stored in one of the 8 registers of the integrator corresponding to 40-69,70-99, 100-124, 125-149, 150-176, 177-199, 200-224 and 225-300 beats.min^{-1}. The 8th register range (225-300 beats.min^{-1}) is used as a quality control of ECG transmission, storing unstable signals.
A second control during the experiment is used by inserting an earphone into the integrator. If the electrodes are properly set, a regular bleep is heard.

The operating principle can be derived in three sub-units.

1. Amplifier

R-waves of the ECG are picked up by two electrodes. These waves are amplified, filtered and transformed by a preamplifier (A1) into pulses (see Fig. 1), followed by an active bandpassfilter (A2). This filter contains an automatic gain control. The QRS amplitude at the output of the filter remains constant at variations of electrode potentials between 0.5 and 2.0 mV. The second step is amplitude filtering by a Schmitt-trigger circuit (A3). At this point the analog ECG potential is transduced to a digital signal called "pulse". Third and last step in filtering is done by "MM" a so called nonretriggerable monostable multivibrator. With the resulting standard pulse the desired R-R interval detection is executed.

2. Analyser

This section classifies the beat-to-beat heart rate (R-R interval) in one of the eight preprogrammed ranges of rates (registers). Any pulse called i will start a time mechanism. Next pulse $i + 1$ will be stored in one of the eight registers according to the time length of the R-R interval.

3. Memory

The memory consists of eight registers (CMOS integrated circuits) corresponding to eight ranges. The capacity of each register is 2×10^6 couples of R-R intervals. The read-out unit automatically multiplies the register reading by two resulting in the total amount of heart beats on the display panel.

The heartbeat integrator is powered by four mercury cells type RM 575-H which are frequently used in hearing aids. Thanks to a low power consumption of 0.5 mW, uninterrupted operation is permitted up to three weeks.

C. Read-Out Unit

The read-out console has only two control buttons: "Start" and "Next". Besides an indicator "Battery empty" and a numerical display, seven digits are required for the register contents and one digit for the corresponding register number. At the end of an experiment the integrator is inserted into the integrator connector at the front panel of the read-out unit (see Fig. 4). About 5 s after starting (which is done by pressing the illuminated button "Start"), the following results appear on the display: Register number: 1. Register contents: the amount of heartbeats specific for a range.

As soon as the apparatus has read out the first register, which takes about 5 s, the button "Next" will be illuminated. When the operator presses the "Next" button, the content of the following register appears on the display. Meanwhile the read-out cycle of the next register is initiated.

In the busy state both control buttons (including the illumination) are electronically switched off in order to prevent damage of register data by operator error (reading out is a destructive procedure). Moreover, the charge condition of the inserted integrator is checked. If the voltage has approached an unsafe level a red indicator "battery empty" is illuminated.

At the end of this procedure the integrator is ready to use again.

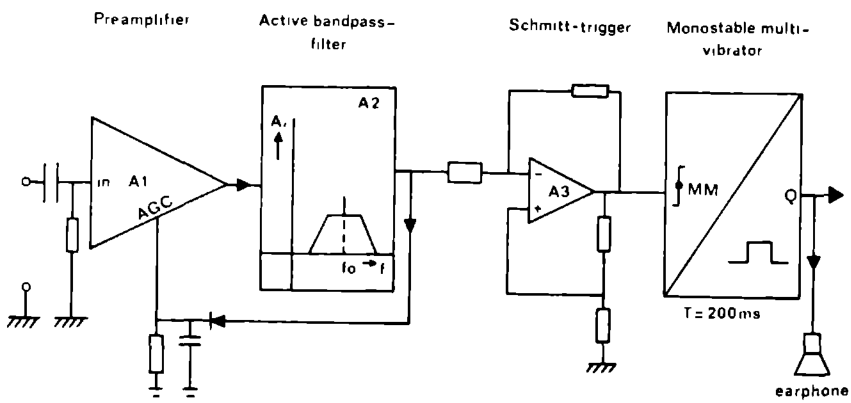

Figure 1. Analog circuit.

RESULTS

System Evaluation

During the past year the accuracy of the heart rate integrator has been tested repeatedly with a generator (TEM Instruments, London, England), which generates from 25-300 beats.min^{-1}. On all occasions the measured beats in the different registers were found to be the actual ones within $\pm$ 5 beats. In order to test the integrator in a more physiological way, the ECG was recorded on tape. Some segments of these recordings contained ECG's in rest, others contained ECG's recorded during periods of heavy work, especially during high arm and chest muscle activity. There were also segments recording inadequate ECG measurements due to electrodes which were improperly fixed to the skin. The total number of heartbeats was counted manually by acoustic monitoring. To know the counts in the eight heartbeat registers, the tapes were recorded with a precision rate meter and the percentages were calculated per range. The results of repeatedly monitoring these two standard tapes with the integrator are shown in Table 1.

At this time, the instrument has been evaluated in several treadmill studies involving healthy children and adults. The subjects wore the integrator in a pocket, in addition ECG was recorded simultaneously on magnetic tape (Philips, Holland). The total heartbeat count was calculated manually by acoustic monitoring. Figure 2 shows, as expected, a very close relationship between the total heartbeat count when measured with both methods. However, two tests (●) were not taken into account because the 8th level of the integrator, the so called "Quality level", contained more than 3.0 % of the total registered heartbeats. In both tests there were some problems with the electrode fixation.

In order to determine how the children would react to wear a heartbeat integrator a small experiment was set up with twenty healthy kindergarten children (age 5 yrs.). During four subsequent schooldays the children received a pedometer (Tsagometre, USSR), sealed in a pocket. The pedometer was attached to the waist. This instrument records vertical movements (Stunkard, 1960). One day in the same week each child also received a heartbeat integrator in addition to the pedometer. The results are tabulated in Table 2. It was seen that there were no differences in pedometer results, with or without the heartbeat integrator, suggesting that the children were at least not hindered in their daily activities when wearing the heart-

Table 1. Integrator results of several tests (n=8) with standard ECG. Tapes checked by acoustic monitoring and rate meter.

Hr register	Rate range	Tape I (45 min)			Tape II (27 min)		
		Integrator read out		Rate meter (%)	Integrator read out		Rate meter (%)
		Mean $\pm$ S.D.	% of total beats		Mean $\pm$ S.D.	% of total beats	
1	40- 69	22 $\pm$ 2.4	0.4	0.5	40 $\pm$ 3.7	1.1	1.0
2	70- 99	715 $\pm$ 3.8	12.2	12.5	180 $\pm$ 3.3	5.2	5.0
3	100-124	1781 $\pm$ 8.5	30.3	30.5	613 $\pm$ 3.8	17.7	17.5
4	125-149	1584 $\pm$ 8.0	27.0	26.5	1107 $\pm$ 4.5	32.0	32.5
5	150-176	1015 $\pm$ 4.7	17.3	17.0	858 $\pm$ 5.6	24.8	25.0
6	177-199	691 $\pm$ 2.8	11.8	12.0	497 $\pm$ 3.4	14.4	14.0
7	200-224	51 $\pm$ 3.6	0.9	1.0	119 $\pm$ 2.0	3.5	3.0
8	225-300	15 $\pm$ 2.1	0.3	0.0	45 $\pm$ 2.8	1.3	2.0
Total beats		5874 $\pm$ 8.2			3459 $\pm$ 7.3		
Acoustic monitoring		5870			3419		

Table 2. Pedometer scores per day of four consecutive days and during one day when the children (n=20 ages 5 yrs.) also carried the heartbeat integrator.

	n	Pedometer score (units) per day		
		Mean score over 4 days Mean ± S.D.	Score on day while Mean ± S.D.	t
Boys	9	11,579 ± 2,646	11,906 ± 4,287	0.39[a]
Girls	11	9,177 ± 1,759	9,475 ± 2,237	0.70[a]
Total	20	10,258 ± 2,465	10,569 ± 3,451	0.72[a]

[a]Not significantly different at a 0.05 level.

beat integrator

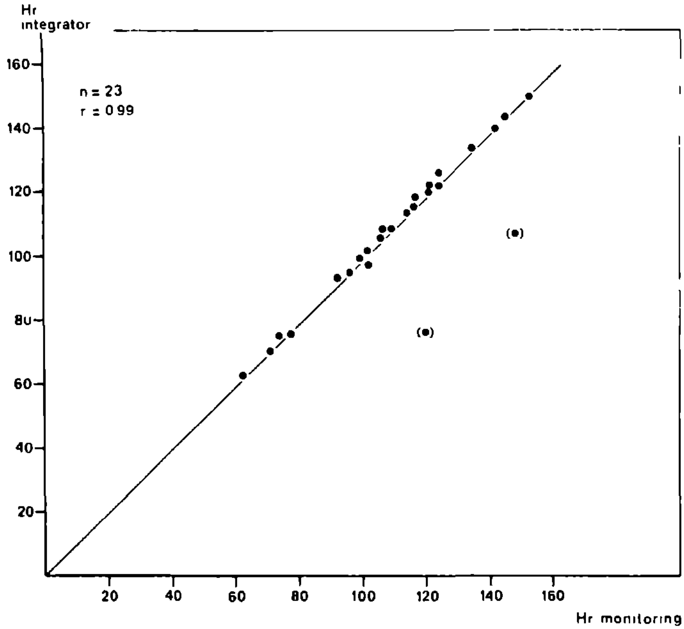

Figure 2. Relation between mean heart rate obtained from integrator and manually acoustic monitoring.

Some Typical Results

Figure 3 shows three results of the heartbeat integrator used by adult males during ca. 9 hrs. In addition to these measurements, their activities were written down in an activity diary (Durnin et al., 1967). Every time when there was a change of activity, it was recorded in the diary. In this way the energy expenditure per minute could be calculated using the energy expenditure tables. It is clear that subject C was the most active of the three examples; his mean heart rate is higher (144 against 118 and 115)

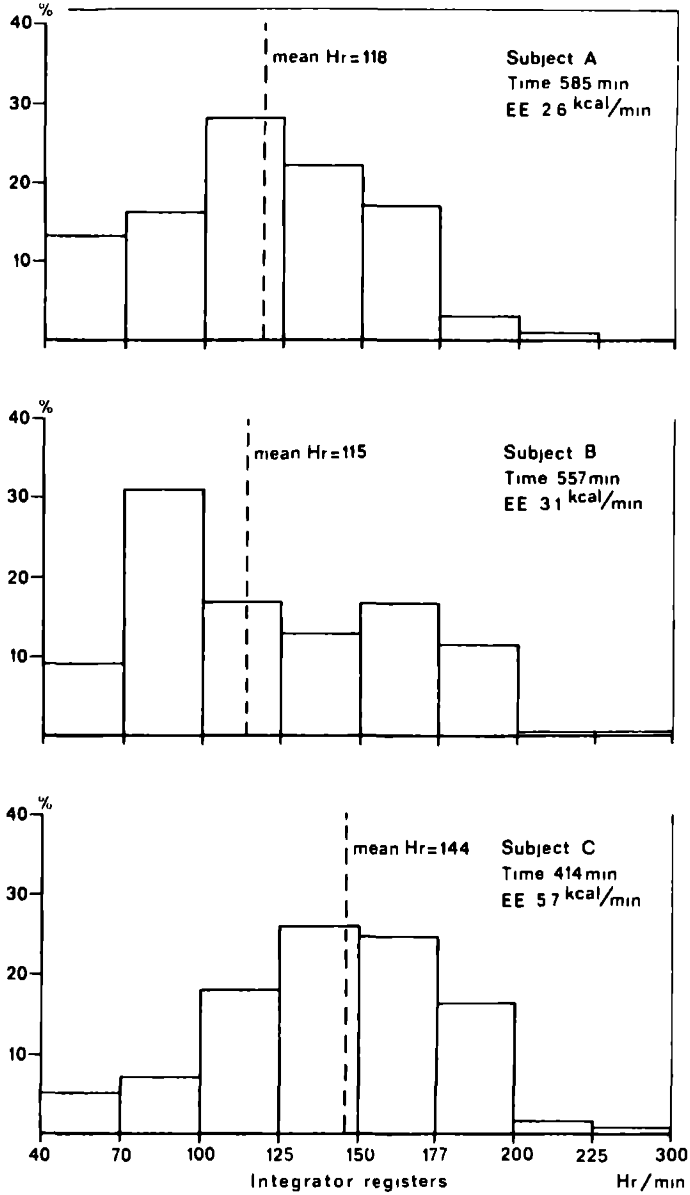

Figure 3. Frequency distribution of total heartbeats per register, mean heart rate, measuring time and the energy expenditure (E.E. in kcal.min^{-1}) calculated from the activity diary in three adult males.

and the frequency distribution shows a shift to the right, compared with subject A and B, while the individual energy expenditure (E.E.), as measured by the diary, also tends to a higher value compared with subjects A and B.

Subject A and B have nearly the same mean heart rate. However, from the detailed integrator results, it was seen that subject B spend more time with a higher heart rate: According to this, the activity diary result was higher for subject B.

DISCUSSION

To ensure the adaptability of this technique to a variety of field situations it was necessary to develop a device which was very small, accurate and light weight, yet ruggedly constructed. This was especially true in our case where the group of interest are children from 4-12 years of age. Reviewing the literature it was clear that most instruments which have been developed were not suitable for the research of physical activity in children. Therefore we decided to construct an apparatus, which was a compromise between both principles of heartbeat registration as mentioned before.

The result is a seven level heartbeat integrator of very small size and weight, easy to use and capable of measuring up to 3 weeks without changing the batteries or resetting the counter (see Fig. 4). The whole system has been tested and used now for a year. During this evaluation period Mansourian et al. (1975) described a similar integrator: A 8-level heartbeat integrator using a three electrode system without an automatic gain control and "Quality register". The major problem of integrator design stems from the need to build in as many control systems as possible, because it is very difficult to recognize errors after the experiment is completed and also to minimize ensuing feelings of frustation.

The first objects of quality control are the electrodes. A two electrode system was chosen to minimize the chance of getting improper signals and to save preparation time. These are important factors in epidemiological field work. Checking the sensitivity and resistance is of course a part of the basic preparation technique. The automatic gain control can be

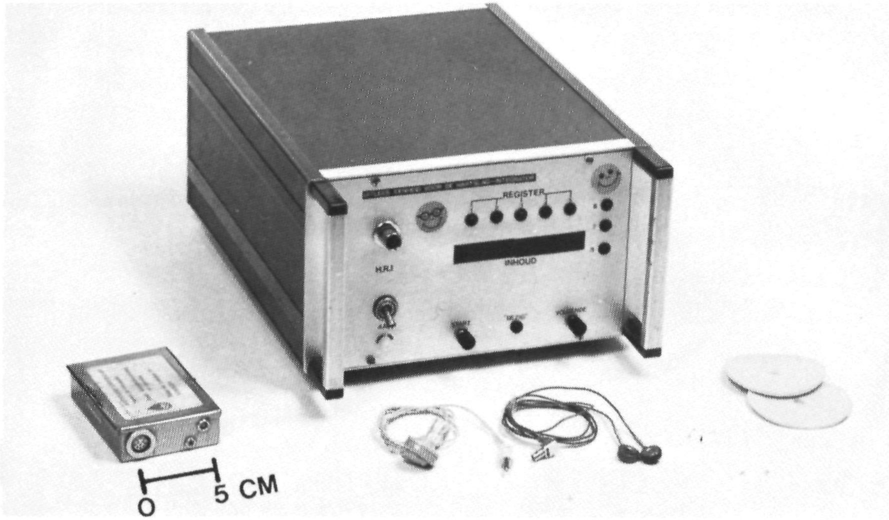

Figure 4. Picture of the complete system.

considered as a second quality factor. It prevents missing QRS peaks due to for instance respiratory variations of amplitude. False triggering at T-waves occurs very rarely, because of the attenuation of the bandpass filter.

One disadvantage of this system is that for short times after large amplitude events (2 mV or more) the amplifier gain may be too low for sudden small amplitudes, i.e. below 1 mV. As a result total measured heartbeat may be somewhat lower than actual. From the results with the standard tape II on which some large amplitude events are recorded, it can be seen that in this case the influence of this error source on the total accuracy is not detectable.

The earphone can be considered as a third signal control. It is tapped after the signals are filtered and transformed into standard pulses. In this way, the filtered signal can be controlled during or out of the experimental period.

During the preparation procedure it was checked whether heavy arm and breast muscle activity caused any irregular bleeps. When this happened other precordial positions (V1-V2) were tested. During the experiment itself the subjects (adults) listened once in a while for irregular bleeps, avoiding time consuming control visits. A very important check point after the experiment is completed, is the content of the "Quality register". All counts in this register with a range of 225-300 beats.min^{-1} can be considered as non-heart-rate triggers. Muscle noise and introduced mains interference especially will give counts in this register. Because the whole system has a "dead time" of 0.2 s, rates over 300 beats.min^{-1} cannot be detected. If the 8th register yields a high score (more than 2 % of the total count) the results of the experiment must be considered as unreliable.

A final control is to calculate the experimental time from the mean register heartbeat value (for example 112.5 for register 3) and the result of the same register. In the study with 20 children (age 5 yrs.) the difference was +0.04 % $\pm$ 1.38. The operating range of the integrator can be in error by as much as about 10 beats mainly due to electrode contact bounce. The chosen cross-over levels between two registers were very stable with a maximal error of $\pm$ 0.4 beats.min^{-1}. This error was constant over the whole range of cross-over levels.

Disadvantage in the use of this apparatus is the impossibility to analyse the relation between heart rate and time during the recording period. The results are given over the total period. A further disadvantage of this storage system is the destructive read-out procedure. The read-out unit cannot store permanently the obtained data.

In over 150 studies with children during 24 hrs. or more this heartbeat integrator has been proven to be a reliable and simple method of recording the heart rate. The apparatus was well received by all participants (children and adults). Most seemed to enjoy the experience. Using the pedometer as parameter for physical activity it was shown that this group of little children did not behave differently in terms of movements when wearing an integrator. In these experiments it turns out that one investigator was able to study the activity of 15 subjects per day using the heartbeat integrator.

In summary this system appears to be a valuable method in the study of daily physical activity of groups of children or adults.

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Chapter 4.2.

A PORTABLE MINIATURE SOLID-STATE HEART RATE RECORDER FOR MONITORING DAILY PHYSICAL ACTIVITY

W.H.M.Saris, P.Snel, J.Baecke, F.van Waesberghe and R.A.Binkhorst

(published in Biotelemetry 4, 131-140, 1977)

SUMMARY

A compact, rugged, solid-state heart rate recorder (63x94x22 mm, 195 g) to measure normal daily heart rates over periods of up to 33 hrs. is described. With an interval switch a selection can be made for a mean heart rate over 30, 60 or 120 s. The ECG amplifier filter is equipped with an automatic gain control to eliminate R-wave amplitude changes during physical activity. A continuous acoustic check on correct electrode attachment and sufficient signal amplitude is possible by means of an earphone. Data may be stored on punch tape, tape recorder, or processed on-line, or plotted directly on a line writer to obtain a heart rate profile over the measured time. In 45 studies with adults and children the heart rate recorder has proven to be a reliable instrument.

Key words: Portable solid-state heart rate recorder - Storage telemetry - Ambulant monitoring - Heart rate - Daily physical activity - Energy expenditure.

INTRODUCTION

Improvements in the recording of the daily physical activity in terms of energy expenditure have been the subject of several reports over the past 10 years (Seliger, 1976). Besides questionnaires (Heinilä et al., 1965) or simple devices like the pedometer (Stunkard, 1960), the most promising method for a simple and rapid estimation seems to be the indirect-indirect calorimetry using regression equations, that relate the heart rate to the rate of energy expenditure (Edholm, 1966). Besides the need of exercise tests to establish the individual regression equation between heart rate and energy expenditure (i.e. oxygen consumption), an apparatus is needed to record the heart rate over at least 24 hrs. The devices used to record heart rate over long periods of time are based principally on two methods: the first one is recording the total beats per day (Baker et al., 1967; Rowley et al., 1959) or the summed beats in consecutive heart rate ranges (Mansourian et al., 1975; Saris et al., 1977). The second method is based on recording the heart rate on time base for instance by means of tape recorders (Rutenfranz et al., 1977) or telemetry (Geeseman et al., 1971). Telemetry over 24 hrs. does not seem to be adequate in this type of experiment, because it is difficult to have the receiver continuously in the neighbourhood of the transmitter (i.e. subject), which it should. Thus, recording on a device carried by the subject himself seems to be the best solution. Tape recorders do meet this requirement, especially since relatively small-sized apparatuses are commercially available. A drawback is that often these recorders and their read-out units are expensive. Furthermore, the recorder contains moving parts giving an inherent chance on faults due to mechanical shocks, pollution, abrasion and so on. Moreover, the weight is too high, especially for children. The purpose of this paper is to describe the development and evaluation of a solid-state recording system of the heart rate plus a processing and display unit, in which these problems are solved.

MATERIALS AND METHODS

General System

The ECG is picked up with a two chest electrode system. The number of R-waves is counted per time interval and stored sequentially in the heart rate recorder. Power is supplied by mercury cells. The read-out unit may be connected to different devices for data storage while on-line processing is also possible.

Heart Rate Recorder

A block diagram is shown in Figure 1. Each R-wave is amplified, filtered and counted. Every minute (or if desired every ½ or 2 min) the sum of counted R-waves is stored in a solid-state memory.

Due to our requirement of using a two electrode system the input signal must be filtered thoroughly. The first manipulation with the electrode signal is amplification and frequency filtering. This is done by an AC-coupled preamplifier with a high cut off frequency at 20 Hz and by an active bandpassfilter. The amplitude of the signal from this filter is kept constant by a control loop. This loop is closed by a peak detector, the output voltage of which controls the gain of the preamplifier. Its setpoint level is adjusted only once. In this way the R-waves between 0.5 and 2.0 mV can be read from the ECG whatever its amplitude variations may be (Fig. 2).

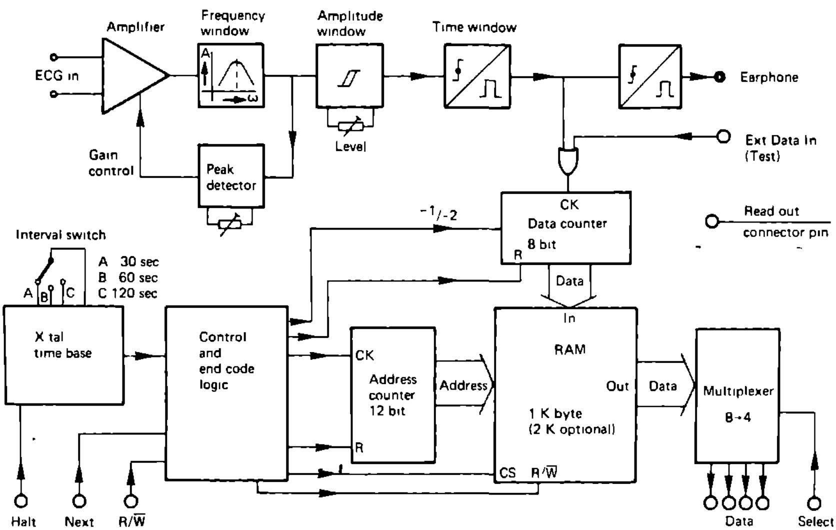

Figure 1. Block diagram of the heart rate recorder.

The second step is amplitude filtering or level detection by means of a Schmitt-trigger circuit (amplitude window in Figure 1). At this point the analog ECG voltage is transformed into a digital signal. The analog circuits, described so far, are designed to be insensitive to variations of battery voltage.

The third and last step in filtering is the application of a non-retriggerable-monostable multivibrator in order to establish a time window. Its input-pulse forces the output to go "high". Subsequently it will remain "high" for a fixed period of time, uninfluenced by the input. The time constant of this circuit (250 m s) determines the highest heart rate that will be accepted (about 240 beats.min^{-1}). With the resulting standard pulse the desired R-wave detection is completed.

The digital section has been realized with 20 CMOS integrated circuits, compactly assembled, yet servicable. The main part of this section is a 1,000x8 bit random access memory (RAM). It can store 8 bits data from the data counter in one of the 1,000 RAM locations, indicated by the address counter.

A crystal controlled "time base circuit" can be programmed easily with an interval switch for one output pulse every 30, 60 or 120 s. When the heart rate recorder is inserted into the read-out unit the time base circuit will be stopped automatically by a "Halt-line" as long as the recorder is inserted.

The "control and end code" circuit is formed by several logic elements and has two tasks: 1. to make the other circuits perform correctly at the right time, and 2. to insert a specific "end code" into the RAM when a measurement is completed. The "R/W" signal from the read-out unit forces the memory to read data and to transfer this information to the multiplexer, or to write data from the data counter into the memory cells.

The "Next" signal increments the address counter. It also initiates a "chip select" (CS) signal to the memory to read or write data. Finally this signal resets the data counter to zero.

The input pulses for the data counter can either come from ECG circuit or from the read-out connector pin indexed with "Ext Data In". Using this input the whole digital system can be checked quickly.

The output of the address counter is directed to a memory location and is incremented by the interval pulse from the time base circuit. This

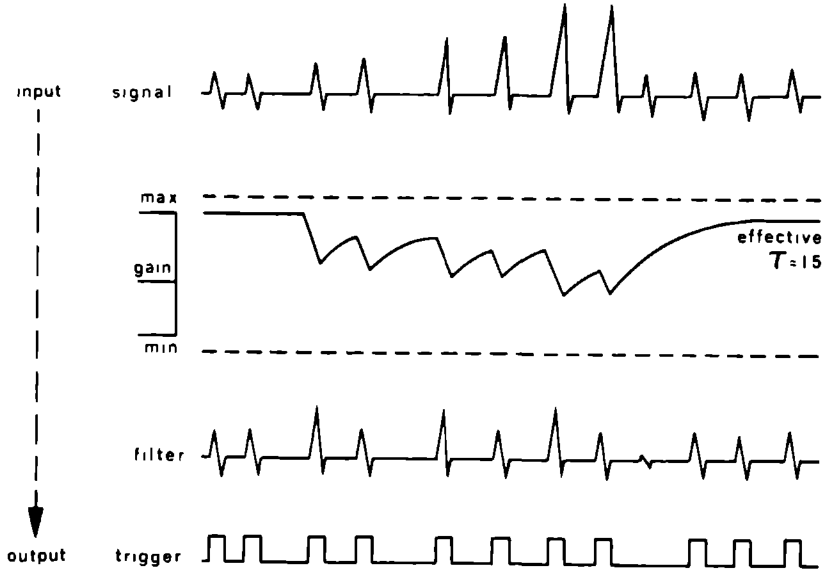

Figure 2. Scheme of ECG filtering using automatic gain control.

counter is reset to zero whenever the "R/W" signal changes state.

When the interval switch is set to 120 s, the control logic will automatically switch the data counter to a divide-by-two mode in order to prevent overflow (8 bits represent a maximum of 256 counts). Whenever a sum of counted pulses in the chosen interval period is stored in the memory, the data counter is reset to zero.

In order to cut down on the number of pins of the read-out connector the output data byte from RAM are sequentially cut into two parts by means of a multiplexer. Via a "Select" line the read-out unit can select either the left or right four bits of an output byte. This heart rate recorder is powered by four mercury cells type RM 575-H such as are frequently used in hearing aids. Thanks to a low power consumption (i.e. 1.5 mW) uninterrupted operation is permitted over at least 10 days. Weight and size of the recorder are 195 g, 63x94x22 mm.

Read-Out Unit

Main function of this part of the system is to retrieve the data from the memory one by one, visualizing them on a display and sending them at the same time to a data storage medium. Instantaneous data storage is needed because pulling out the heart rate recorder from the read-out unit means clearing the memory. This automatic function was build in to prevent false resetting during the experiments.

Of course, some design criteria were different from those of the recorder; simple control and protection against operator mistakes were accentuated over low power consumption or small dimensions. The read-out unit was constructed in a conventional manner without any special features. The read-out procedure may be controlled by five push buttons; 1. End code (first action is writing and end code in the memory); 2. Start (reading results at a rate determined by the output mode selection switch); 3. Stop (reading out is stopped as soon as the previous number is fully displayed); 4. Go on (read-out procedure will go on); 5. Return to zero (the address counter is reset to zero and another start command is possible). All functions are electronically blocked when their operation is not allowed. So destruction of a data file by an operator mistake is impossible. During any read-out cycle the heart rate results accompanied with the sequential period of recording may be observed on a display in the read-out unit.

Experimental Procedure

Since the heart rate recorder has an automatic gain control it is not necessary to select the electrode location more carefully than normal to emphasize the R-wave and to minimize the T-wave. We mostly use the manubrium sterni and the ictus. The skin is carefully swabbed with alcohol and abraded. Small mass electrodes (Saris et al., 1977) filled with electrode jelly are attached to the skin with double stick discs (3M Co., Minn.). The electrode-skin resistance should be lower than 10 kΩ. The whole recorder system (from electrodes up to batteries) is working correct when a bleep tone at heartbeat frequency is heard via an earphone inserted into the recorder. This will not influence the recording. Finally a larger glued foam-plastic disc (Steier, Elmshorn, FRG) is stuck over the electrodes. The application and checking procedure takes 15 min. Figure 3 (left side)

Figure 3. a. 5-year-old boy with the miniature heart rate recorder in a side-pocket. b. Recorder with batteries, earphone, electrodes and read-out unit.

shows a 5-year-old child carrying the device in a side-pocket attached to a belt around the waist. After selection of the output mode, the recorder is inserted into the read-out connector of the unit. After pressing the illuminated buttons "End code" and "Start" the results appear on the display. Simultaneously the data is stored in the selected output mode. The read-out procedure takes about 3 min.

Computing Hard- and Software

Data storage is possible by means of a teletype, papertape puncher, digital cassette, tape recorder and an input-output channel of a computer system. Associated supporting software was developed for analysing data by a large computer. The following system functions were programmed: error detection in the data field (no physiological results below 30 or above 225 beats.min^{-1}), time spent in the different heart rate ranges and the associated percentage of the total period. These data may also be printed in graphic display (Fig. 4). Furthermore, the data are stored and readily available for additional analysis, which may be desired at a later stage.

All these systems are digital. Therefore, in the read-out unit provisions were made for an analog output for use with a two-channel pen-recorder; one channel for heart rate and the other for time base.

RESULTS

During the past months the accuracy of the heart rate recorder has been tested repeatedly with a pulse generator, which generates from 25 till 300 beats.min^{-1}. On all occasions the measured heart rate had an error of up to $\pm$ 0.48 %. Another calibration experiment was carried out with ECG signals from a magnetic tape in order to validate the recorder in a more physiological way. This tape contained a continuous ECG recording of a subject performing all sorts of activities at different intensities. There were also recording periods with artefacts due to electrodes which were improperly fixed to the skin. The total amount of heart beats was counted manually by acoustic monitoring. As a result of repeatedly testing (n=14) with this standard tape the measured total number of heart beats was 5,839 $\pm$ 18.2. The calculated mean heart rate is 130 beats.min^{-1}. Counting manually by listening to this tape gave a total of 5,870 beats. This means 131 beats.min^{-1}.

As an example of the technique outlined above, Figure 4a illustrates the day's heart rate profile plot of an adult subject (27 years) participating in an experiment. In Figure 4b a heart rate profile of a 5-year-old girl at kindergarten is presented.

To date, the instrument has been used in about 45 studies on daily physical activity of 5-year-old children up to adults. From the total 1,082 measured hours about 15 min showed values above 210 or below 30 beats.min^{-1}.

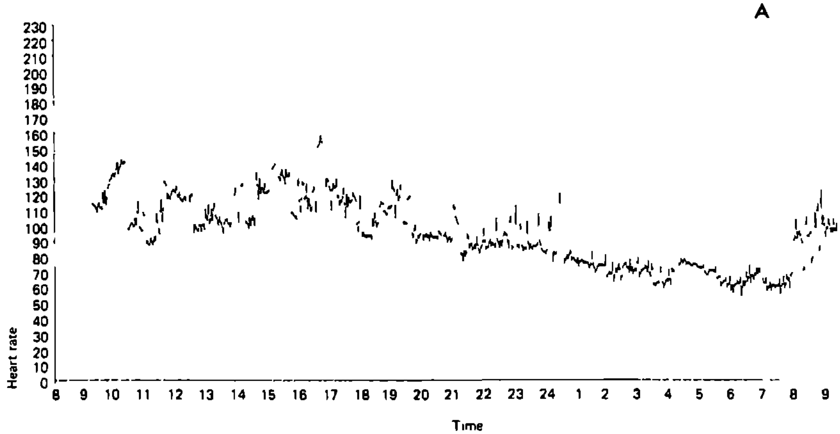

Figure 4a.

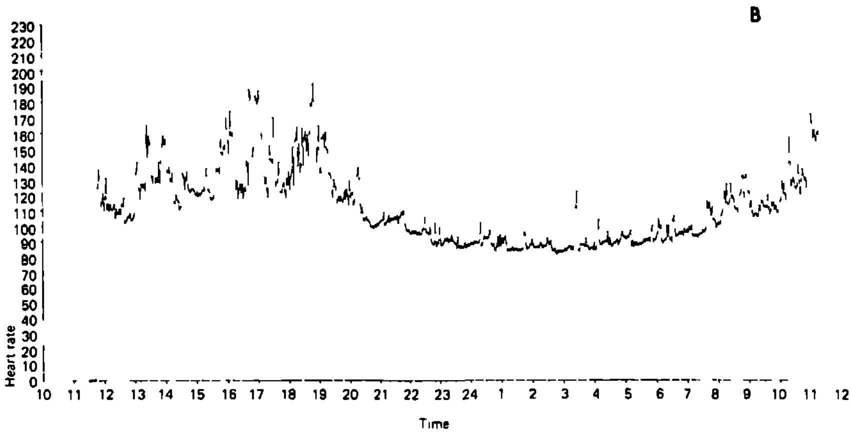

Figure 4b.

Figure 4. 24 hrs. heart rate profile, each point is the mean of 2 min, time distribution of 11 heart rate ranges and time that heart rate is below or above physiological levels (index of mistakes).

A. Results 27-year-old man

heart rate (beats.min^{-1})	time (min)	percent of total
30-49	4	0
50-59	12	1
60-69	192	13
70-79	244	17
80-89	164	11
90-99	228	16
100-124	460	31
125-149	148	10
150-176	10	1
177-199	0	0
200-225	0	0
Total time	1,462	

Number of minutes with heart rates of below 30 beats.min^{-1}: 0. Number of minutes with heart rates of above 225 beats.min^{-1}: 0.

B. Results 5-year-old girl

heart rate (beats.min^{-1})	time (min)	percent of total
30-49	0	0
50-59	2	0
60-69	0	0
70-79	0	0
80-89	284	20
90-99	274	19
100-124	472	33
125-149	250	18
150-176	110	8
177-199	22	2
200-225	0	0
Total time	1,414	

Number of minutes with heart rates of below 30 beats.min^{-1}: 12. Number of minutes with heart rates of above 225 beats.min^{-1}: 0.

DISCUSSION

It is clear that the adaptability of heart rate recordings in all kinds of field situations depends in the first place on the social acceptability of the apparatus. Therefore, a very small size and light weight was the first condition for constructing this new device. When we started 4 years ago with the development of a portable heart rate recorder it was clear at that moment, that only a heart rate integrator could meet these requirements. Therefore, an integrator was built in which eight CMOS counters were needed for storage of the interbeat interval in eight ranges (Saris et al., 1977). The disadvantage of this system is the impossibility to plot heart rate against time. Since that time, due to the trend of increasing integration density in the semiconductor technology, it became possible to construct a small device storing a large number of addresses. The result is the described device with a capacity of 1,000 addresses, capable of storing heart rate data sequentially up to 33 hrs. When needed this capacity can be doubled at the expense of a one third increase of content. To resume some features: many controls are built in to minimize bad operation, the automatic gain control prevents missing QRS complexes, the earphone to check acoustically the whole analog system during recording, and the read-out unit with different data transfer modes.

It is clear that heart rate in itself is not a measure of energy expenditure, but it seems to be usable for the estimation of it. Firstly it is necessary to determine the relationship - which is unique for each subject - between heart rate and energy expenditure (i.e. oxygen consumption). From the daily heart rate recordings energy expenditure may be estimated. Therefore, it is necessary to analyze the vast amount of heart rate data automatically. The principal computing objectives thus include the frequency distribution of the heart rate, the presentation of the heart rate related to time and the calculations from heart rate to energy expenditure.

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Chapter 4.3.

RECORDING THE HEART RATE BY R-R TIME INTERVAL VS. BEATS PER MINUTE IN STUDYING DAILY PHYSICAL ACTIVITY

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(Biotelemetry: submitted)

SUMMARY

Different types of portable heart rate recorders (not E.C.G. systems) are currently being used in the investigation of daily physical activity. They are based on two principles: 1. recording the mean number of beats or R-R intervals per time period and 2. recording and storing each R-R time interval, expressed in H.R., in a H.R. range register. Until now results obtained from the different systems were compared without taking into account the different measurement principles.

This report concerns the investigation of simultaneous measurements of the H.R. of 13 healthy 10-year-old children, using the two recording systems during a normal school day. There are no significant differences between the two systems with respect to the number of beats in the different heart rate ranges. Moreover, the results of the calculated energy expenditure (E.E.) are of the same magnitude. The study demonstrated that, both recording principles give virtually identical results for the investigation of daily E.E.

Key words: Heart rate - Heart rate recorders - Daily physical activiy.

INTRODUCTION

The use of heart rate recording as a method for estimating daily physical activity has received more and more attention in recent years (Bradfield, 1971). This, along with the rapid developments in the area of microelectronics, has lead to the present use of different types of heart rate recorders for research (Rutenfranz et al., 1977).

This is usually based upon the recording of the total number of counts per measurement period (usually 1 minute), which results in a mean heart rate (H.R.) per minute. There are also systems that are based on recording the R-R time interval. When translated into H.R. per minute, this information can be stored in a frequency register, for example, 70-99 beats.min^{-1} (see Table 2).

Both principles are used for estimating daily activities and for predicting energy expenditure (E.E.). Failure to take into account the difference between the measurement principles can lead to conflicting results. It can be expected that brief changes in H.R. will be detected in a R-R time interval system and stored in the appropriate register whereas these will hardly (or not at all) influence the mean H.R. in the other system.

To investigate the extent to which this difference in measurement principle can lead to conflicting results, both systems were applied in a study with a group of school children during a normal school day. Furthermore, the consequences for predicting the daily E.E. is discussed.

METHODS

Subjects

13 Healthy 10-year-old children (8 boys and 5 girls), participating in a longitudinal study, were asked to wear two recorders, instead of one, after the routine measurements including a maximal exercise test and 24-hour heart rate recording (Saris et al., 1980), during a normal school day. Antropometric data for these children are given in Table 1.

Recorders

The heart rate was registered with two types of recorders:

1. A heart rate integrator (H.R.I.), (Depex, de Bilt, The Netherlands), which is based upon the measurement of the R-R time interval and the storage of the counts converted to beats.min^{-1} in 7 registers 40-69, 70-99, 100-124, 125-149, 150-176, 177-199 and 200-224 respectively. An 8th register, the so-called quality register, is added because it is very difficult

Table 1. Physical characteristics of the 13 children (mean and range).

Age (yrs.)	Height (cm)	Weight (kg)	Body fat (%)
10.2	141.2	32.5	14.1
9.6-10.6	133.4-149.0	28.1-39.6	5.5-25.3

to recognize errors after the experiment is completed. All counts in this register, with a range of 225-300 beats.min^{-1}, can be considered as non-heart rate triggers. Muscle noise and introduced mains interference will especially give counts in this register. If the 8th register yields a high score (more than 2 % of the total counts) the results of the total experiment are considered to be unreliable (Saris et al., 1977 A).

2. A heart rate memory system (H.R.M.), (Depex, de Bilt, The Netherlands), that is adjusted to the measurement of the mean H.R. per 2 minutes. The results are given in H.R.min^{-1} (Saris et al., 1977 B).

In order to be able to compare both systems, the time spent in the 7 heart rate ranges is calculated. The mean H.R. and actual time spent in the different heart rate registers is calculated for the H.R.M. system with the aid of a software program as described by Saris et al. (1977 B). It is not possible to calculate the actual time per register for the H.R.I. system because the exact mean H.R. per register is unknown. From a pilot study with the H.R.M. the mean H.R. per register was set at 60, 82.5, 112.5, 137.5, 163, 187.5 and 212.5 for register 1 through 7 respectively. Dividing the total number of counts per register by this mean value (beats.min^{-1}) gives the time spent per register. Comparing the total estimated time with the actual measuring time is another check for a normal recording of the 24-hour heart rate. In general the difference is less than 5 % of 1440 minutes (one day).

Both systems have an automatic gain control so that very precise placement of the electrodes (2 for each system) is not necessary for obtaining a good signal. The skin was carefully swabbed with propyl-alcohol and abraded to give a low resistance. Disposable low resistance electrodes (NMD corp., Ohio, U.S.A.) were used. Both instruments were worn without problems in two side-pockets attached to a belt around the waist: the children were rather keen to have two instead of one recorder.

Energy Expenditure

Determination of the energy expenditure (E.E.) over the entire day is based upon the prediction of the E.E. from the H.R. measured per register over the entire day. The following procedure was used to convert H.R. to E.E. The H.R. and E.E. were individually measured during standing and at 3 work-loads during the treadmill test. The relationship between the two was determined with a linear regression equation; E.E.= a + b H.R. It is then possible to substitute the estimated mean H.R. per register in the regression line and to calculate the E.E. for each register using the calculated time per H.R. register. Since this relationship between H.R. and E.E. is not linear in the lower heart rate ranges (Booyens et al., 1960), the regression equation was only applied for register 4 through 7 of the H.R. frequency range 125-224 beats.min^{-1}. The E.E. value for standing was used as the average value for the lighter activities for frequencies below 125 beats.min^{-1} (register 1 through 3). The sum of the calculated E.E. per register gives the E.E. per 24 hours.

E.E. (kcal) was calculated from oxygen consumption ($\dot{V}_{O_2}$): $\dot{V}_{O_2}$x4.9 (caloric equivalent of 1 l.O_2). The $\dot{V}_{O_2}$ was measured with an automatical O_2-, CO_2, Ventilation analyzing system (Oxycon-4, Mijnhardt, Odijk, The Netherlands).

Statistical analysis: To compare the values of the two systems, the student's *t*-test for paired data was used. A probability level of $p<0.05$ is considered to be significant.

RESULTS

Figure 1 shows the number of counts per register for both systems measured over a 24-hour period for this group of 13 children.

There are no significant differences between the two systems in the mean number of beats in each of the registers. However, there is a tendency for the H.R.M. system to produce higher values for register 2 and 3 (70-124 beats.min^{-1}), while the H.R.I. system registers more beats in the lower and higher H.R. ranges.

Moreover the results of the calculated E.E. are shown in Table 2. As could be expected from the data in Figure 1, no significant differences were found.

DISCUSSION

Different principles for measuring H.R. for obtaining an indication of

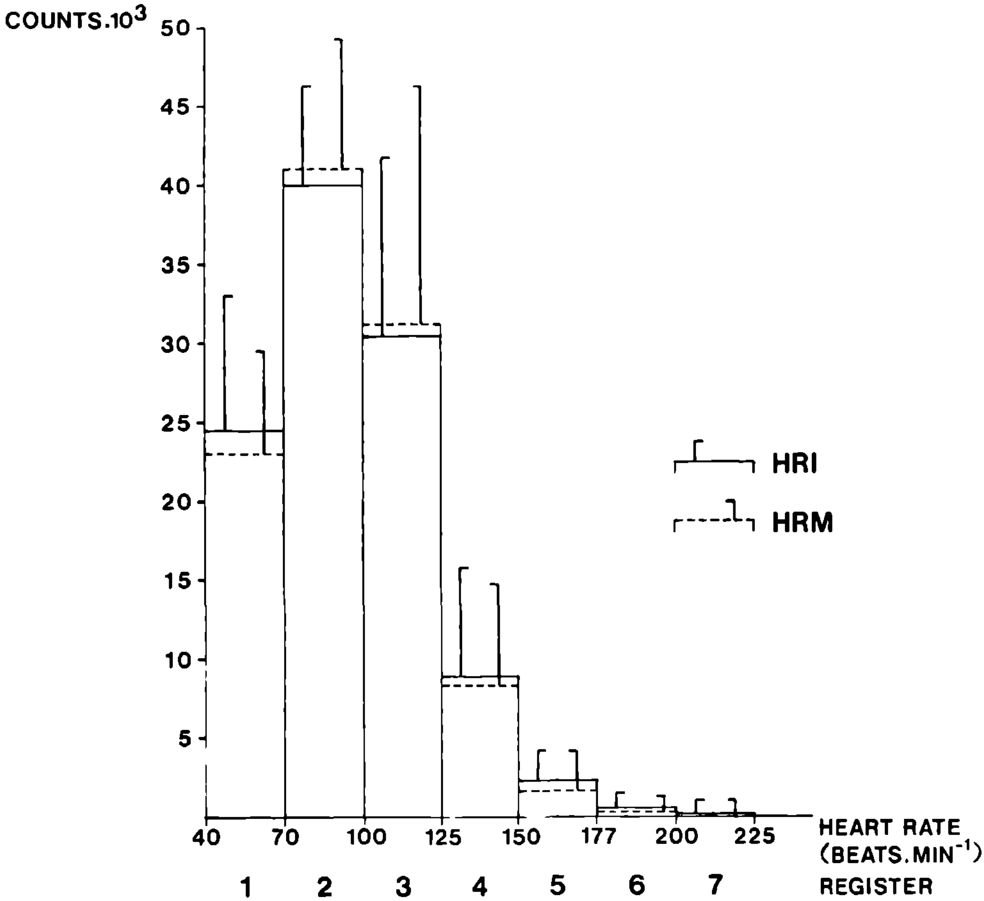

Figure 1. Total number of counts per heart rate register for the R-R interval system (H.R.I.) and the mean H.R. per 2 minutes (H.R.M.). The mean values and standard deviations (represented by vertical bars) are given for the 13 children.

Table 2. Mean ($\pm$ S.D.) of 24-hour energy expenditure (E.E., kcal) calculated from the H.R. in each register collected from simultaneous measurements with the H.R.I. and H.R.M. recording systems, see text.

Register	H.R.-range	Energy expenditure (kcal) from		
Number	(beats.min^{-1})	H.R.I.	H.R.M.	Student-t
1	40- 69	515 $\pm$ 228	484 $\pm$ 225	n.s.
2	70- 99	837 $\pm$ 135	861 $\pm$ 169	n.s.
3	100-124	349 $\pm$ 156	358 $\pm$ 197	n.s.
4	125-149	268 $\pm$ 194	259 $\pm$ 193	n.s.
5	150-176	86 $\pm$ 81	63 $\pm$ 56	n.s.
6	177-199	25 $\pm$ 41	19 $\pm$ 46	n.s.
7	200-224	14 $\pm$ 35	11 $\pm$ 38	n.s.
Total E.E.		2091 $\pm$ 442	2056 $\pm$ 417	n.s.
E.E. per minute		1.46 $\pm$ 0.31	1.43 $\pm$ 0.29	n.s.

physical activity are in use (Lange Andersen et al., 1978). Until now, results obtained from different systems were compared without taking into account the different measurement principles. When measuring the R-R time interval each change in frequency will be detected and recorded in the appropriate register in the H.R.I. system. Systems in which the mean number of beats per time period are recorded will not be influenced if these changes are of short duration. These brief variations in the H.R. can be caused by a number of physiological factors such as changes in blood pressure and respiration (Sayers, 1973). Spontaneous variations occur especially in resting H.R. There is less variation during exercise. In rest the sinus arrhytmia resulting from respiration is well known ; these give large differences in R-R time interval, while the mean H.R. is hardly influenced.

Especially for the H.R.M. system, it can be expected on theoretical grounds that the measured counts.min^{-1} concentrate around the mean H.R. over a 24-hour period. Although there was a tendency for the H.R.M. system to have higher values in registers 2 and 3 and lower values (Figure 1) in the low and high heart rate ranges, none of the differences was significant. The number of counts in the higher heart rate registers is small for both systems. Because of that, possible differences in H.R. between the two systems become so small as to have no effect on the total 24-hour measurement. Only 5 % of the total E.E. is spent at a H.R. level higher than 150 beats.min^{-1} (see Table 2).

In conclusion, our results show that, although differences could have been expected in measured mean H.R. and R-R time intervals, the two systems produce comparable results.

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VALIDITY OF THE ASSESSMENT OF ENERGY EXPENDITURE FROM HEART RATE

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(Amer.J.clin.Nutr.: submitted)

SUMMARY

The heart rate (H.R.) method for the assessment of the energy expenditure (E.E.) (i.e. calculating E.E. by means of H.R. from a previously individual assessed regression equation between H.R. and E.E. as during standardized activities) of 13 free-living subjects has been evaluated. Actual E.E. was measured continuously during a 5-hour experiment. During a 24-hour period (including the 5-hour experiment) the E.E. of the remaining 19 hours was estimated from activity diaries. Different approaches were used to obtain the individual relationship between H.R. and E.E. The approaches were based on one or two regression lines and calculated on standard calibration measurements including postural activities, three levels of exercise on the bicycle ergometer or treadmill or data from the 5-hour period.

The most accurate prediction of E.E. from H.R. was obtained from the equation based on 5 activities from the 5-hour period ranging from sitting to moderate exercise: mean difference ± S.D. between predicted and actual E.E. was +1.9 ± 6.7 % and +0.1 ± 23.6 % for the 24-hour period. Predicted E.E. of light activities was considerably over-estimated when these follow more heavy activities, possibly due to a different response of H.R. and oxygen consumption.

The results suggested that when only a group mean value of E.E. is required the H.R. method is a usefull and non-burdening method, provided that the regression equation used for the prediction is based on calibration measurements during activities which are as similar as possible to those to be measured.

Key words: Heart rate - Energy expenditure - Daily physical activity.

INTRODUCTION

There is an increasing interest in assessing daily physical activity and daily energy expenditure. The indirect calorimetry combined with the activity diary are accepted methods for measuring energy expenditure and physical activity under free-living conditions. Unfortunately, these methods have a number of disadvantages such as wearing a mouthpiece and equipment for determining the oxygen consumption. Furthermore, it is known that keeping an activity diary is not a simple matter; it leads quickly to inaccurate recording and may also influence the daily activities.

An alternative method which has been applied more often in recent years is the heart rate method (Bradfield, 1971 A). With this method, the heart rate (H.R.) is recorded during the experimental period and an attempt is made to estimate the energy expenditure (E.E.) by means of the previously determined relationship (calibration curve) between H.R. and oxygen consumption ($\dot{V}_{O_2}$) for standard activities.

The great advantage of this method is the complete freedom of experimental subjects. Wearing the small H.R.-monitor is practically of no hindrance to daily activity. The real problem with this method is transforming H.R. to E.E. by means of calibration curves.

It is necessary to establish individual calibration curves because of inter-individual differences (Åstrand, 1952). There appear to be some problems with the H.R. method with respect to the transformation of H.R. to E.E. Firstly, intra-individual variations related to workload (Booyens et al., 1960) and the different relationships between H.R. vs. $\dot{V}_{O_2}$ at different postures and activities such as arm or leg activities (Andrews, 1967) should be considered. Different mathematical relationships, such as the use of a number of linear regression equations (Warhold and Lenner, 1979; Acheson et al., 1980) or an exponential relationship (Dauncey and James, 1979), are suggested in order to make the transformation from H.R. to E.E. as accurately as possible.

The problem arises, of choosing the types of activities necessary to make possible a good calibration between H.R. and $\dot{V}_{O_2}$. On the one hand, standard activities are used such as stepping on a bench (Bradfield, 1971 B; Spady, 1971) and on the other hand it is emphasized that the calibration activities should be as representative as possible for the activities to be measured (Acheson et al., 1980). A second problem which has received little attention is the effect of a continuous change in duration, intensity and type of activity and the corresponding change in H.R. and $\dot{V}_{O_2}$, each with a different response time on the validity of the prediction. Because of the problems mentioned above, it is clear that the H.R. method is not yet securely established.

The object of this study was to evaluate the validity of the different calibration methods for predicting the E.E. from H.R. during a period of 5 hours while the subjects carried out a large number of activities during which the oxygen consumption was measured. Furthermore, the prediction methods applied were evaluated for a period of 24 hours.

METHODS

Subjects

Twelve male and one female volunteer(s) between 21 and 28 years of age participated in this study. All of the subjects were familiar with the experimental procedures. Table 1 shows the average antropometric indices and ranges. The percentage of body fat was calculated using 4 skinfolds according to the method used by Durnin and Womersly (1974).

Calibration with Standard Activities

Simultaneous measurements of H.R. and E.E. were performed during various standard activities the day before and after the experimental day. Resting metabolic rate was measured for 30 minutes after a resting period of one hour after the subject's arrival at the laboratory. Subsequently, the H.R. and E.E. were measured during a 15-minute period of quiet reading in an easy chair and while standing and being encouraged to make some relaxing movements with the arms and legs. After these three so-called quiet activities, three steady state measurements were made on the treadmill and three on the bicycle ergometer. The workload was individually adjusted so that

Table 1. Antropometric data of the subjects. Mean and range.

Sex	n	Age (yrs.)	Height (cm)	Weight (kg)	Body fat (%)
males	12	24.5	1.79	73.7	12.7
		22-28	1.69-1.92	62-88	8-19
female	1	21	1.71	56.1	22.5

H.R.'s of 90-100, 115-125 and 140-150 beats.min^{-1}, respectively, were reached. During the treadmill exercise the load was increased by raising the slope.

Experiment

In the experimental period E.E. and H.R. was measured for approximately five hours. This period was divided into four sessions (I - IV) of 55 to 80 minutes, two sessions in the morning and two sessions in the afternoon. In order to give the subjects the opportunity to take a drink or to eat lunch, three breaks were given between the four sessions, varying from 15 to 90 minutes. The room temperature and the clothing of the subjects were the same as during the calibration procedure. During the 5-hour measurement period, a number of activities were alternated, varying from sitting to submaximal exercise (Table 2). Activities were recorded in an activity diary for the remaining 19 hours of the experimental day. The subjects were free to do as they pleased during this time.

Apparatuses

During calibration expired air was collected in Douglas-bags during the last minute of the activity. The volume of expired air was measured in a Tissot-spirometer and gasanalyses were performed with a paramagnetic O_2-analyzer (Servomex, England) and an infra-red CO_2-analyzer (URAS, Hartmann and Braun, West-Germany). The $\dot{V}_{O_2}$ during the 5-hour experiment was measured continuously using the Kofranyi-Michaelis (K-M) respirometer. The respirometer was calibrated against the Douglas-bag method and showed no significant differences in the range applied.

The expired air was collected with a mouthpiece and a low resistance valve. The sample bag was changed and the respirometer was read during the last 30 s of each activity. Gasanalyses were performed as described. The respirometer was not worn by the subjects, but was placed next to him or her. For bicycling, the respirometer was fastened to the bicycle in a special basket. To calculate the E.E. in kcal the $\dot{V}_{O_2}$ was multiplied by the factor 4.9 (i.e. caloric equivalent for 1 $l.O_2$).

In order to estimate E.E. during the 24-hour period, the activity diary was used for the 19 hours spent outside of the 5-hour measurement period. Each subject carefully recorded the activities according to the Edholm scale (1966) The individually determined $\dot{V}_{O_2}$ values, measured during the

Table 2. Outline of the activity pattern carried out by each subject during the 5-hour period.

Session	Code	Activity	Time (min)
I	A	standing[1)]	0-19
	B	treadmill load II[2)]	20-34
	C	bicycle ergometer load I[2)]	35-49
	D	sitting[3)]	50-69
II	E	sitting	0-19
	F	cycling[4)]	20-39
	G	treadmill load I	40-54
	H	standing	55-74
III	I	standing	0-19
	J	treadmill load II	20-39
	K	cycling	40-59
	L	sitting	60-79
IV	M	sitting	0-19
	N	bicycle ergometer load II	20-39
	O	treadmill load I	40-59

[1)] Allowed to move arms and legs

[2)] Slope load I and II elicited a H.R. of about 120 beats.min^{-1} and 150 beats.min^{-1} respectively.

[3)] In a comfortable chair, reading or doing handwork.

[4)] Subject was free to choose speed and route to cycle.

calibration procedure, were used to calculate the E.E. for lying and sitting activities. The values given by Bink et al. (1966) were used for the other activities. These values are based on data given in the literature.

Heart rate was continuously recorded during the standard activities by using a conventional electro-cardiogram apparatus. The H.R. was measured during the 24-hour lasting experiment with a solid-state heart rate memory system (Saris et al., 1977). The memory was read 24 hours later and analyzed by computer (Saris et al., 1977). The H.R. data were divided into 11 H.R. distribution-levels: 40-49, 50-59, 60-69, 70-79, 80-89, 90-99, 100-124, 125-149, 150-176, 177-199 and 200-225 beats.min^{-1}. It was possible to calculate the mean H.R. and H.R. distribution for separate activities with the recorded time at the beginning and end of the different activity periods during the experiment.

Prediction of the E.E. from H.R.

The E.E. is calculated from H.R. during the 5-hour and the total 24-hour period by means of ten different relationships between H.R. and E.E. for each individual.

Methods (see Figure 1):

1. Linear regression equation based on the three calibration points on the treadmill;
2. Linear regression equation based on the three calibration points on the bicycle ergometer;
3. Linear regression equation based on the calibration points lying, sitting and standing and the three points on the treadmill;
4. Linear regression equation based on the calibration points lying, sitting and standing and three points on the bicycle ergometer;
5. In order to find the transition point from one relationship between H.R. and E.E. to another at the change from quiet activities to more dynamic activities, the results of the 5-hour period were plotted individually (see for example, for subject 9, method 9, in Figure 1).

From these plots the H.R. during standing proved to be a good indicator for this transition point. Therefore, the H.R. during standing for each subject was rounded off in line with the divisions of H.R. levels (see section Apparatuses). For example, a H.R. of 88 beats.min^{-1} during standing, was rounded off to 90 beats.min^{-1}. Below this H.R. transition point the

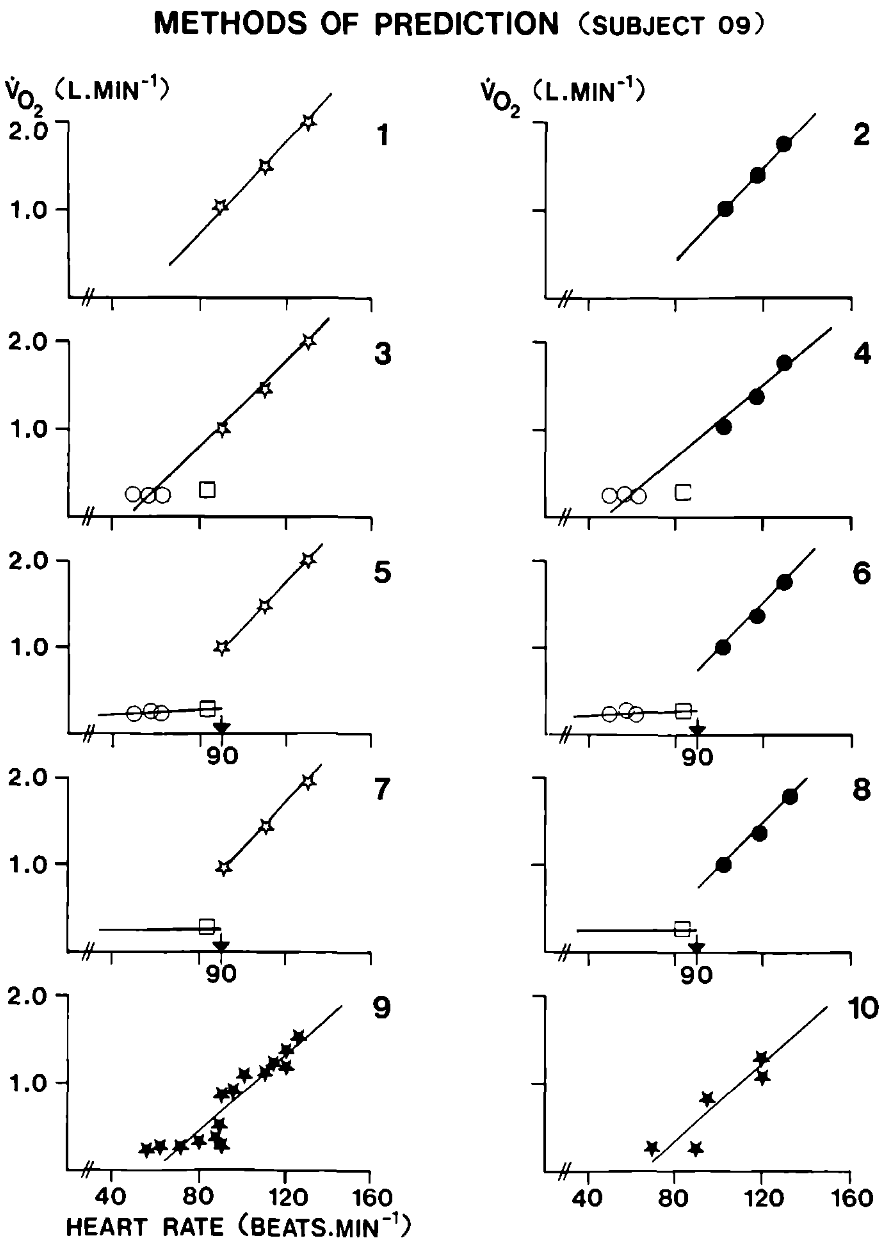
METHODS OF PREDICTION (SUBJECT 09)
$\dot{V}_{O_2}$ (L.MIN^{-1})
2.0
1.0
1
2
3
4
5
6
7
8
9
10
90
40
80
120
160
HEART RATE (BEATS.MIN^{-1})

Figure 1. An example of the individual relationship between H.R. and $\dot{V}_{O_2}$ to show the different methods of prediction for subject 09. Standard calibration activities for the different methods of prediction were: treadmill exercise (✡) and bicycle ergometer exercise (●), lying, sitting in a comfortable chair and sitting on the bicycle ergometer (○) and standing (□), and measurement points (✱) from the 5-hour period.
For details about methods of prediction 1-10, see text.

linear regression equation based on the calibration points lying, sitting and standing was used. For the periods spent with a H.R. higher than this transition point the linear regression equation as mentioned in method 1 was used.

6. H.R. lower than the H.R. transition point: see method 5. Higher than the H.R. transition point: see method 2.
7. Measuring H.R. and E.E. during lying, sitting and standing is time consuming. Therefore, during the periods spent with a H.R. lower than the transition point, the E.E. value of the calibration point standing was used, instead of a regression equation. For the H.R. higher than the H.R. transition point: see method 1.
8. H.R. lower than the H.R. transition point: see method 7. Higher than the H.R. transition point: see method 2.
9. The E.E. was calculated from the mean H.R. during the experimental period and the individual regression line based on the 15 measurement points (see Table 2) during the 5-hour period.
10. The mean H.R. was inserted in the individual linear regression line based on 5 representative measurement points during the 5-hour period in order to reduce the number of measurement points: two quiet activities, standing and sitting, A and E respectively, and two moderate bicycle ergometer activities, C and N respectively, and cycling free, activity F.

RESULTS

5-Hour and 24-Hour Period

The actual measured E.E. and the mean H.R. found during the 5-hour period are shown in Table 3. Also the estimated E.E. for the 24-hour period is shown in this table along with the corresponding mean H.R.

The mean (± S.D.) of the individual differences between the predicted and actual E.E., expressed as a percentage of the actual E.E., are shown for all 10 methods of prediction in Figure 2, for the 5-hour period as well as for the 24-hour period.

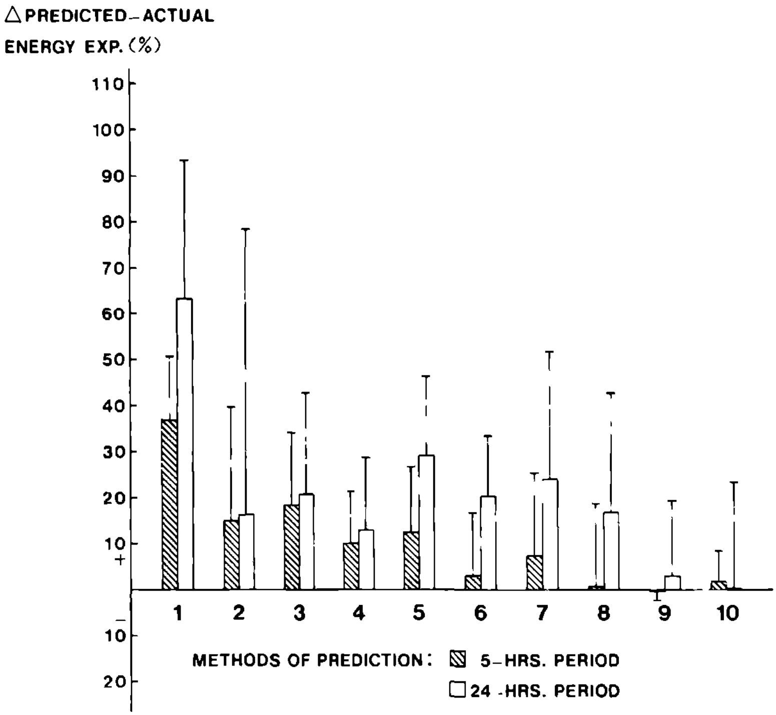

Figure 2. Difference between predicted minus actual energy expenditure as percentage of the actual values for the 5-hour period (▧), and the 24-hour period (□) for the 10 methods of prediction (see Figure 1). Mean values and standard deviation (vertical bars), of 13 subjects.

Table 3. Heart rate and energy expenditure during the 5-hour and 24-hour period for 13 subjects[1].

Period	Heart rate (beats.min^{-1}) Mean		S.D.	Energy expenditure (kcal.min^{-1}) Mean		S.D.
5-hrs.	94.1	±	10.7	3.96	±	0.50
24-hrs.[2]	80.1	±	12.1	2.22	±	0.23

[1]During the 24-hour period the results of 1 subject were excluded because of improper H.R. recording during the night.

[2]The E.E. for the 24-hour period was calculated from the 5-hour period and the activity diary for the remaining 19 hours.

In general it can be stated that the E.E. is overestimated by the prediction from H.R., but there are large differences in results between the prediction methods. If we accept a mean difference of 10 % from the actual value, then methods 4, 6, 8, 9 and 10 have smaller mean deviations from the actual E.E. for the 5-hour period. The S.D. is between 10 and 20 %, except for methods 9 and 10 which have lower values. The results for the 24-hour period indicate that only methods 9 and 10 have a mean deviation of less than 10 % from the actual value. The S.D. is larger than that of the 5-hour period. All other methods have mean deviations greater than 10 % up to about 63 % for method 1.

Although not presented in Figure 2, we also calculated the predicted E.E. from measurement points independent from the actual measured E.E. period. Therefore, as in method 10, we selected 5 points (activities I, K, M, N and O) from sections 3 and 4 to calculate the individual regression equation. This equation was used to predict the E.E. during sessions 1 and 2 (the split-half procedure). The mean ($\pm$ S.D.) of the individual differences between the predicted and actual E.E. expressed as percentage of the actual E.E. during sessions 1 and 2 for the 5-hour period and 24-hour period were -3.7 ± 19.5 and $+1.8 \pm 26.5$ respectively.
The mean differences of this split-half procedure are nearly the same as the mean results obtained from method 10, although, the standard deviation is greater.

Changing Activities

In order to get an impression of the effect of changing the intensity of the activities on the accuracy of the prediction methods, the actual E.E. is plotted for each activity in the order in which the activities were performed during the 5-hour experiment (see Table 2), against the values predicted by methods 1 and 4 (Figure 3A and 3B). The results of methods 1 and 4 are shown in Figure 3 because these are representative for the other methods. A general trend for each activity was present in all 10 prediction methods. However, the degree to which the effect was present depended upon the precision with which the actual E.E. could be predicted for the entire period. It appeared that the prediction of energy expenditure during considerable physical activity was in better agreement with the actual E.E. (see activity B, C, F and G in Figure 3A and J, N and O in Figure 3B).

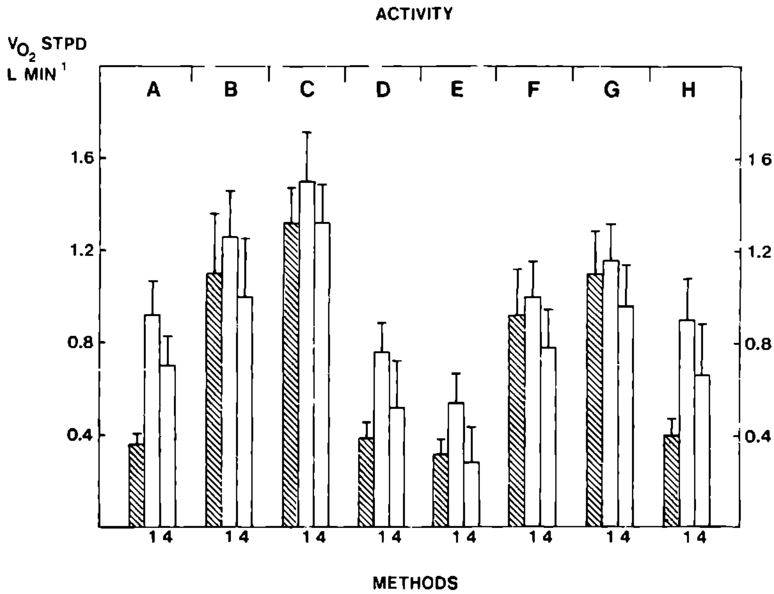

Figure 3A.

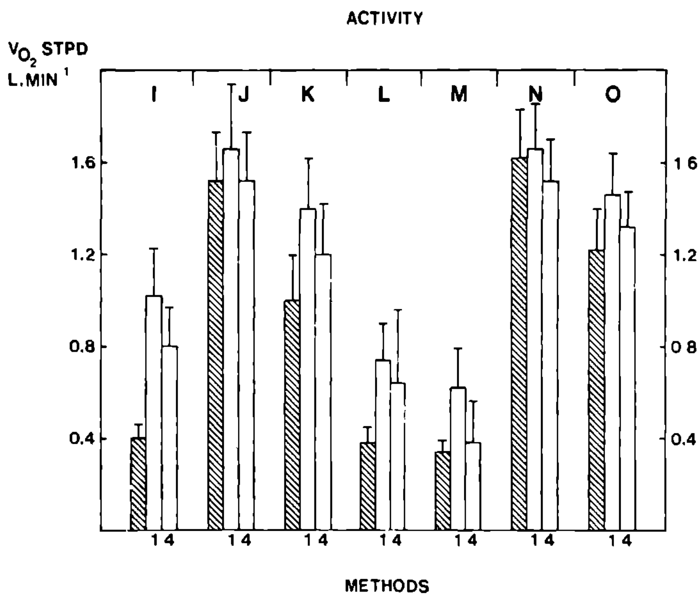

Figure 3B.

Figure 3A and 3B. Actual oxygen consumption (▧) and predicted values for method 1 and method 4 (see text) for all consecutive activities (see Table 2) A-H during the morning session and I-O during the afternoon session.
Mean values and standard deviation (vertical bars) of 13 subjects.

Especially for quiet activities after moderate exercise, such as for sitting (D and L) after the activities C and K, the E.E. is overestimated compared with the subsequent period of sitting (E and M respectively). The largest differences between measured and predicted values occurred during the 3 standing periods A, H and I. It seems that these deviations are constant and not related to the precedinq activity.

DISCUSSION

Measuring energy expenditure in free-living subjects is often a difficult and frustrating undertaking (Garrow, 1974). The usual methods such as respirometry or the activity diaries require a large amount of cooperation from the subjects. The heart rate method seems, in this respect, an attractive alternative for measurements in the field. Technological developments are such that H.R. can be recorded reliably over long periods of time. It is however still necessary to pay extra attention to attaching the electrodes (Hanish et al., 1971).

However, the interpretation of H.R. readings remains a problem. In the range of low H.R. and E.E. the relation follows a different course than in the higher range, as can be seen in the results of subject 09 (method 9, Figure 1). Therefore, some researchers have proposed working with 2 regression equations instead of one: one equation for the quiet activities and one equation for exercise (Booyens and Hervey, 1960). We used this approach in methods 5, 6, 7 and 8. The problem of determining the H.R. at which a clear change in the H.R. - E.E. relationship can be found was individually solved. The H.R. while standing proved to be a good indicator for the transition point (see method 5). In this group of subjects this transition point ranged from 70

to 100 beats.min^{-1} (mean 89.1 beats.min^{-1}).
In order to keep the calibration procedure for methods 7 and 8 as simple as possible and to work with a transition point, the E.E. while standing was chosen as the average value for quiet activities.

E.E. Prediction of the 5-Hour Period

Contrary to most other studies in this area, it was possible to compare the predicted energy values over a period of 5 hours through a precise measurement of the actual E.E. A period with a mean energy expenditure of 3.96 kcal.min^{-1} and an H.R. of 94.1 beats.min^{-1} (see Table 3) can be characterized as active.

As can be seen in Figure 2, all methods in which the bicycle ergometer calibration results are used provide results which deviate less from the measured values than those methods in which treadmill results are used. Two periods of free cycling but no free walking activities were included in the 5-hour period. The mean results of methods 9 and 10 and the split-half procedure (in which only points from the measurement period itself are used), show good agreement with the actual E.E. These findings support the conclusions of Warhold and Lenner (1977) and Acheson et al. (1980) that the calibration activities must imitate the activities to be measured as much as possible. No experimental evidence about temperature, special positions of the body during work and isometric work has, however, been obtained to support this idea. These situations are especially related to occupational activities. Therefore, the method should be considered very carefully when applied in an occupational setting. It can concluded from the relatively large standard deviations in the prediction methods with an acceptable mean result, that the method appears to be suitable for the measurement of the E.E. of groups, but is unacceptable for the determination of an individual's value . No clear statement can be made regarding the question of the necessity of 1 or 2 regression equations on the basis of the data from the 5-hour period. Methods 6 and 8, based on 2 regression lines, as well as methods 9, 10 and the split-half procedure based on one regression line, provide good results.

E.E. Prediction of the 24-Hour Period

The energy expenditure is calculated by means of the activity diary. The reference E.E. will therefore also be less valid than that of the 5-hour period. For this reason the variation in the percentage difference between predicted and actual E.E. is considerably greater.

The results of methods 9 and 10 and the split-half procedure clearly show, however, that the use of 1 or more regression equations and the choice of standard calibration activities are possibly less relevant than the choice of a number of activities which correspond as much as possible with the activities to be estimated. Acheson et al. (1980) formulated it as follows:

"Using regression lines derived from specialized activities to predict the E.E. of normal activities from heart rate would be naive".

Changes in the Activities

A phenomenon that has received little attention until now is the influence of changes in intensity of the activities upon the prediction of E.E. In this study as well as in the study of Dauncey and James (1979) in which E.E. could be measured, it is striking that the predicted E.E. is usually overestimated. There is a smaller difference between actual and predicted values during the more strenuous activities B, C, F, G, J, N and O in Figure 3A and 3B and larger during less active periods A, D, H, I and L. The large differences appear in periods of quiet activity directly following a period of moderate exercise such as activities D and L.
This is possibly the result of differences in the response of H.R. and $\dot{V}_{O_2}$ when changing from one level of activity to the other, as shown by Brodan and Kuhn (1966). Another cause of the overestimation can be the influence of the posture on the relationship H.R. - E.E. An increase in H.R. and consequently the predicted E.E. appeared during standing, possibly as a result of the pooling of blood in the extremities, without a proportionate increase in the actual E.E. (see Figure 3, activity A, H and I). A correction in the prediction of the E.E. by establishing the activity periods with these types of postures by means of a diary or observation could possibly improve the results. One has however to consider the fact that the recording of activities possibly unfavorably influence the pattern of physical

activity. Furthermore, it is necessary to record the time very accurately if the correction will be usefull. Finally the differences in the measurement of the calibration points during the standard activities and during the 5-hour period have to be considered. H.R. and E.E. was measured in steady state during the standard calibration procedure. However, during the 5-hour period, H.R. and E.E. was measured during the whole period including the first non-steady state minutes. Therefore, these differences may also contribute to an overestimation by most of the prediction methods.

In conclusion, the present study shows the value of the H.R. method as a measurement instrument for determining the mean E.E. in group studies. The simplicity of the method and the speed at which data can be collected together with the advantage that the subjects experience practically no hindrance, compensate for the disadvantage of the large individual errors. Therefore, although the method is of little value for the work physiologist, it is of value for the nutritionist or epidemiologist. Choosing calibration activities which are as close as possible to the actual activities to be measured is essential for obtaining valid results.

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DETERMINING THE INDIVIDUAL VARIATION IN ENERGY METABOLISM IN 8-YEAR-OLD CHILDREN BY TWO PREDICTION METHODS

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SUMMARY

The aim of the study was to compare inter- and intra-individual variation in energy expenditure (E.E.) and energy intake (E.I.) recorded over a period of 24 hours.

E.E. was estimated from the 24-hour heart rate recordings in about 800 children, 8 years of age. The 24-hour recall method was used for the E.I. The intra-individual variation of the E.E. was estimated in a subsample of 46 children from measurements during 2 consecutive days. The intra-individual variance of the E.I. was based on data from the literature.

The coefficient of variation (C.V.) of E.E. and E.I. (14 % and 25 % respectively) was about the same for both sexes. However, the C.V. of E.E. was about 50 % lower than the C.V. of E.I. The intra-individual variance as percentage of the total variance of E.E. in boys and in girls was 34.4 and 19.4 % respectively. This is far less than the described 50 % intra-individual variance of E.I. for both sexes.

It is suggested that, when the level of energy metabolism is the independent variable in large-scale studies, the 24-hour E.E. recording method should be prefered over the 24-hour E.I. recording method.

Key words: Energy expenditure - Energy intake - Individual variation - Heart rate - Children.

INTRODUCTION

Our interest in this subject arises from a desire for more information about the sources of variance in daily energy expenditure (E.E.) and energy intake (E.I.). In large-scale studies of which this is a part, it is impossible to investigate the E.E. and E.I. of groups of subjects over a period of several days. Because of limitations in time and money, it is often necessary to limit the measurement period to one day. These limitations on the gathering of data have consequences for estimating the true mean value.

The total variation in daily E.E. or E.I. of a group is a combination of intra- and inter-individual variation. Information about the separate contribution of intra- and inter-individual variation provide better insight into the validity of the estimated values and gives valuable information about which statistical methods are suitable for the analysis of group or individual relationships with other variables, for example, the correlation between E.E. and the aerobic power.

In this respect, up to now the level of energy metabolism in children has been studied using data concerning E.I. (Widdowson, 1947; v.d. Haar and Kromhout, 1978). As far as we know, there are no data for the daily E.E. in young children. This is partly due to the tremendous problems involved in estimating or measuring the daily E.E. in children with the existing methods. Data obtained from activities and times noted in a diary by the child himself are unreliable and equipment used for measuring E.E., such as the K.M. respirometer, is too cumbersome for taking measurements of normal daily activities for the entire day (Lange Andersen et al., 1978). Recently, an alternative method has been developed (Bradfield, 1971); the heart rate (H.R.) method, by means of which the daily E.E. can be assessed from the heart frequencies recorded throughout the day.

With this method it was possible to obtain data concerning the estimated E.E. of a large group of children over a 24-hour period and to compare the results with the E.I. obtained through the 24-hour recall method. Furthermore, it was possible to collect data from a small group of children to study the contribution of the intra- and inter-individual variation to the total variance in E.E. Lastly, a comparison is made between the intra- individual variation for E.E. and that of E.I.

METHODS

Subjects

394 Boys and 407 girls from 30 elementary schools who were participating in a health education study participated in this study on school days.

The mean age (± S.D.) of these children was 8.2 years (± 0.3). 46 Pupils (17 boys and 29 girls) from 2 classes from 2 separate schools were chosen for gathering data concerning day to day variation in E.E. No data were collected for studying this variation in E.I. since there is sufficient information available in the literature of comparable groups of Dutch children (v.d. Haar and Kromhout, 1978).

Techniques

The methods used in this study are the same as those used at this moment in the total project, described partly by Saris et al. (1980) and will be described in detail elsewhere. In essence: the E.I. was recorded using the 24-hour recall method. The recall interviews were performed by a trained dietician. A parent of the subject was asked to recall what the child ate on the day before (Monday, Tuesday, Wednesday or Thursday). The food consumed by the child was noted on special forms using models for portion size etc. The food stuffs were coded according to the UCV coding system and processed by the G.V.O. software programs (Elvers, 1980).

Data pertaining to E.E. were collected by the H.R. method; a heart rate integrator (H.R.I.), with 7 heart rate level registers, was attached to the children during the morning school hours. 24 Hours later the number of beats per register of the H.R.I. was read and the mean time per register calculated using an estimated mean H.R.min^{-1} per register (Saris et al., 1977).

The following procedure was used to convert H.R. into E.E. for those days: the H.R.min^{-1} and E.E.min^{-1} (kcal) were individually measured during standing and at 3 workloads during a treadmill test. The relationship between the two parameters was determined with a linear regression equation: E.E.min^{-1}= a + b H.R.min^{-1}. It is then possible to substitute the mean H.R.min^{-1} per H.R.I. register in the regression line and to calculate the E.E. for each register. Multiplication of E.E.min^{-1} with the calculated mean time per register yields the total E.E. per register. Since this relation between H.R. and E.E. is not linear in the lower heart rate ranges, it was only applied to H.R. registers 4 through 7 of the H.R. frequency range 125-224. The E.E. value for standing was used as a mean value of E.E. for frequencies below 125 beats.min^{-1} (registers 1 through 3) (Saris et al., 1982). The sum of the calculated E.E. per register gives the E.E. per 24 hours. These measurements were made only during the normal school days (Monday through Friday).

Heart rate measurements were taken during 2 consecutive days with a group of 46 children to get a better insight into the intra-individual variation. The children had 5 hours of school during each of these days, without physical education lessons. All the children of the same class received an H.R.I. recorder on the same 2 days. The measurements were made 1 week later in the other school. The weather on the measurement days (early June) was dry and sunny with a temperature of about 20^{o} C.

Statistical Procedure

The following estimations were used to get an idea about the intra-individual variation of E.E. on two consecutive schooldays and the inter-individual variation in the group of 17 boys and 29 girls.

1. $S^2\text{intra} = \dfrac{1}{2(n-1)} \sum_{i=1}^{n} (d_i-\bar{d})^2$ (an unbiased estimate of σ^2intra)

2. $S^2\text{inter} = \dfrac{1}{4(n-1)} \sum_{i=1}^{n} (s_i-\bar{s})^2 - \tfrac{1}{2}S^2\text{intra}$ (an unbiased estimate of σ^2inter)

where d_i = difference in E.E. for subject i between day 1 and day 2,
s_i = sum of E.E. for subject i for day 1 and day 2,
and furthermore,

3. $S^2\text{total} = S^2\text{intra} + S^2\text{inter}$

The frequently calculated estimate $S^2\text{inter} = \dfrac{1}{2n} \sum_{i=1}^{n} d_i^{\,2}$ of σ^2inter was not used because it is biased when there is a day effect.

RESULTS

The total variation in E.E. and of that in E.I., the mean values and the coefficients of variation (C.V.) for the boys and girls are given in Table 1. Although there is a significant difference in E.E. between boys and girls, the coefficients of variation are of the same magnitude. There is also a significant difference between the E.I. of boys and girls and also here the C.V.'s are of the same magnitude. The mean values of E.I. agree with the found values for E.E. The C.V.'s of E.I., on the other hand, are nearly twice as high as those of E.E.

The results of the E.E. during 2 consecutive days for the group of 46 children are shown in Table 2. The mean E.E. values are significantly higher for the boys in this group as well. Furthermore, the C.V.'s are of the same magnitude as those for E.E. in Table 1. The measured energy expenditure on day 1 was, significantly different from that on day 2, only for girls.

In Table 3 are given the absolute intra-individual variance as well as the relative intra-individual variance (absolute divided by the total variance) in E.E. Because of the differences between boys and girls seen in Table 1, these are calculated separately for each sex. The relative intra-individual variance is almost two times greater for boys than for girls.

DISCUSSION

As far as we know, no earlier analysis between data of E.E. and E.I. in young children has been made. Because of the development of the H.R. method, it is possible to estimate the level of E.E. in children during normal daily activities. The disadvantage of this method is the relatively large degree of inaccuracy (10-20 % deviation) in predicting the individual E.E. (Dauncey and James, 1979). In this respect the method is comparable to the 24-hour recall method. Therefore, it is clear that both methods are inadequate to obtain information about the individual balance between intake and expenditure. However, for population studies both methods can give valuable data of the level of energy metabolism.

Comparing the two measurements for this group of children (Table 1) shows that the C.V. of the group E.E. (13.7 %) is lower than of the E.I. (24.3 %). This difference in variation of E.E. and E.I. is possibly the result of a difference in method. The E.E. is more directly estimated, with a physiological

Table 1. Mean (± S.D.) and coefficient of variation (C.V.) of the energy expenditure (E.E.) and intake (E.I.), both per 24 hours, in the total group of 8-year-old children.

	Boys n=397	C.V. (%)	Girls n=408	C.V. (%)	Student-t
E.E. (kcal)	2024 ± 277	13.7	1832 ± 255	13.9	$p<0.001$
E.I. (kcal)	1986 ± 483	24.3	1806 ± 462	25.6	$p<0.001$

Table 2. The energy expenditure (E.E.) (mean ± S.D. and coefficient of variation (C.V.)) on two consecutive schooldays in the subsample of 8-year-old children.

		E.E. (kcal)					
	n	Day 1 Mean ± S.D.	C.V. (%)	Day 2 Mean ± S.D.	C.V. (%)	Difference 1-2	Student-*t*
Boys	17	1882 ± 256	13.6	1960 ± 233	11.9	-39 ± 104	n.s.
Girls	29	1710 ± 260	15.2	1774 ± 254	14.3	-32 ± 80	$p<0.05$
Student-*t* (between boys and girls)		$p<0.05$		$p<0.05$		n.s.	

Table 3. The contribution of the intra-individual variation (S^2intra) to the total variation of the energy expenditure in the subsample of 8-year-old children.

	Intra-individual variances	
	S^2intra	$\frac{S^2\text{intra}}{S^2\text{total}} \cdot 100$
Boys	21.600	34.4
Girls	12.800	19.4

means, and is therefore perhaps more accurate. The E.I. depends on the subject's ability to recall accurately the food consumed. Another reason for the greater variation in E.I. can be pointed out: illness of the subject can lead to a very low E.I. because the subject does not eat, while the E.E. maintains at least at minimum resting metabolism.

Recently, v.d. Haar and Kromhout (1978), in a study with Dutch children, calculated that 50 % of the total variance of the E.I. can be explained by the intra-individual variance. This is in agreement with an early study of Widdowson (1947) and data published with adults (Marr, 1971). Comparing these data of E.I. with our findings on E.E. (19.4 % - 34.4 %) for a comparable group of Dutch children it is suggested that the intra-individual variation in E.E. is clearly less than is the case for E.I.

In large-scale cross-sectional studies the percentile classification is a commonly used statistical technique for analyzing relationships between variables. When individuals are classified into percentile groups, sizeable intra-individual variation may lead to a large number of misclassifications and therefore may mask an existing relation between two variables (Liu et al., 1978). It is, therefore, recommended that if the level of energy metabolism is used as an independent variable in population studies, data should be gathered on the basis of the 24-hour H.R. method rather than on the basis of the 24-hour E.I. recall method.

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Chapter 5

AEROBIC POWER OF HEALTHY 4-18-YEAR-OLD DUTCH CHILDREN[1]

SUMMARY

This chapter provides the preliminary results about reference values for the aerobic power of children. This cross-sectional study was performed with a randomly selected group of children ages 4, 6, 8, 10, 12, 14, 16 and 18 years.

The quetelet index (Q.I.) was used as an index for body fatness and indirect as an indicator for the aerobic power. There was no age/sex pattern with respect to the participation of the children. The Q.I. of the group who did not respond after two letters nor wanted to participate after a personal call or visit, was comparable to the mean Q.I. of the participants. The reasons for not participating were specially studied. It is concluded that there are no indications that the non-participants had a lower aerobic power. The antropometric data of the participants are comparable with the data of other studies in The Netherlands as well as that of earlier reports about aerobic power of children in other countries. Aerobic power was measured with the Bruce treadmill test.

The aerobic power, expressed in $\dot{V}_{O_2}$ max. per kg body weight, increases for boys up to 8 years of age and then remains constant at a level of about 53 $ml.kg^{-1}min^{-1}$. The level is fairly constant for girls from 6 years of age on 45 $ml.kg^{-1}min^{-1}$ and decreases at the age of 16 and 18 years to 43 and 42 $ml.kg^{-1}min^{-1}$ respectively.

Comparison with the results of a randomly selected group of children in Czechoslovakia (1976) and with earlier studies on school groups in The Netherlands (1968), Sweden (1952) and the U.S.A. (1938) revealed no great

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differences in the aerobic power of the children. It is tentatively concluded that since the first study, 30-40 years ago, no evident decline in aerobic power of children in this age group has occured.

Key words: Aerobic power - Treadmill exercise - Reference values - Children.

INTRODUCTION

A good physical performance capacity is generally considered a requirement for maintaining good health: for this reason, through the years, in various applied areas within health care tests have been used with which the response to physical exercise is studied. They are useful clinical methods for detecting and quantifying cardio-respiratory disorders such as congenital heart defects, astma etc. The physical exercise tests also give useful information for guiding the patient during the treatment phase. Another area of application is sports and occupational health medicine, where the emphasis is placed on the relationship between workload and work capacity in work situations and in sports.Finally, there is an increasing interest in physical performance capacity (PPC) in public health care. Lack of physical activity and a decline of the PPC are generally considered as risk indicators for heart and vascular diseases (E.E.C./W.H.O.Commission, 1978).

Comparative material of healthy individuals is indispensable in all of these areas of study such as ours. There is little of such material available about children in The Netherlands certainly compared to other countries. In the 60's, Wafelbakker and Bink (1971) studied aerobic power in groups of boys varying from 10 to 20 years of age. More recently, Kemper et al. (1981) published results of 13-14-year-old high school children. Saris et al. gathered data from 8-10-year-old children (1981 A) and from a group of 13-18-year-old girls in a home economics school (1981 B, unpublished data).

This incomplete picture of the aerobic power of selected groups of Dutch children connected to a large demand for reference values of children, was the impetus for beginning an investigation in 1980 with a randomly selected group of healthy children. At this moment, about half of the target group of children has been studied. With the results of this study, it is possible to make some comparisons with other data in this thesis. Furthermore, it will be possible to make a comparison with the data gathered in The Netherlands 15 years ago (Bink and Wafelbakker, 1968), as well as data collected in Czechoslovakia, also based on a randomly selected sample of the population (Seliger and Bartůněk, 1976), in Sweden (Åstrand, 1952) and in the U.S.A. (Robinson, 1938), 30 and 40 years ago respectively, in order to evaluate the degree to which this aspect of the PPC of children has changed.

METHODS

The Population

This cross-sectional study was performed in Nijmegen. Thanks to the co-operation of the City Health Department it was possible to make a random selection from the total census of people who were 4, 6, 8, 10, 12, 14, 16 and 18 years of age, plus or minus 2 weeks on the day of the experiment. To avoid the possibility that the number of participants from a given age group would decline below a minimum level through refusal, the total sample was 3 times greater than the number necessary for the experiment.

The goal and design of the experiment was explained in a letter to the parents and to the children above the age of 10 years. Furthermore, a letter from the census bureau was enclosed which emphasized that participation was completely voluntary. Parents gave their response by way of an enclosed stamped self-addressed envelop. If no answer was received within 2 weeks, a second letter was sent asking for permission to be given or to give the reasons for refusal.

After the first 3 experimental months, when it appeared that even after the second letter was sent about 15 % had not responded, co-operation was requested by telephone and house calls (Table 1 : call/visit). In this way it would be possible to determine whether there was a correlation between a low PPC and refusal to participate. The reasons for refusal were noted for the group which was personally approached. Also, information was requested concerning membership in sport clubs in the past and present and the height

Table 1. Response and participation of the total group of children that was asked by letter for permission to participate in the study (see text for further explanation).

	Age	Total addresses	Moved	Negative response letter	Negative response call/ visit	Positive response letter	Positive response call/ visit	Not healthy	Refusers during tests
Boys	4	18	2	5	1	5	1	2	2
	6	18	-	4	2	12	-	-	-
	8	18	1	4	2	9	1	1	-
	10	21	1	2	3	13	1	-	1
	12	18	2	4	3	8	-	1	-
	14	20	-	5	-	13	-	1	1
	16	19	-	2	2	13	-	2	-
	18	19	1	5	3	8	2	-	-
Girls	4	18	4	3	2	6	2	1	-
	6	18	2	5	-	7	1	2	1
	8	18	-	4	1	10	1	2	-
	10	15	1	6	1	6	-	1	-
	12	18	-	5	1	11	1	-	-
	14	19	-	3	-	14	-	2	-
	16	19	2	4	3	9	-	1	-
	18	18	-	5	-	10	1	1	1
Total		294	16	66	24	154	11	17	6
				90		165			
%		100	5	31		56		6	2

and weight of the child were asked and, if this was not known, measured.

Table 1 gives a summary of the response and the participation. The reasons for refusing participation are given in Table 2. The reponse "no reason" was noted as such. Table 3 is a summary of the reasons why 17 children were removed from the sample "because of illness". In Table 4 a comparison is made between the quetelet index (Q.I.) of the participants and the non-participants who were personally approached.

Experimental Plan

A general medical examination was performed during the first visit to the laboratory. The questionnaires completed by the parents and partly by the older children concerning medical histories, daily physical activities, participation in sports (by parents as well as children) and occupation of the parents, etc., were checked together with the parents and the children. Antropometric measurements were made: height and weight, the thickness of 4 skinfolds (triceps, biceps, subscapula and crista iliaca) measured with a Holtain calipper, and the percentage fat calculated according to the Durnin and Womersley method (1974). Furthermore, the subjects practiced walking on the treadmill for 5 minutes at different speeds and gradients and the procedure of the maximal test was discussed.

The maximal exercise test on the treadmill was performed during the second visit to the laboratory during the morning hours. The measurements were made in an air-conditioned room at a temperature of 18^{0} C. The scheme developed by Bruce (1963) was used as a test protocol in which every 3 minutes the speed and gradient were increased (see Table 5) until continued running was impossible in spite of encouragement from the test leader. The expired air was collected in Douglas bags during the last (3rd) minute of each workload, except for the first workload and during the last minutes or half minute of maximal exercise before the moment of exhaustion. The collected volume of expired air was measured with a Tissot-spirometer and the gasanalyses were performed with a paramagnetic O_2-analyzer (type Servomex, Taylor, England) and an infra-red CO_2-analyzer (type Uras, Hartmann and Braun, West-Germany). Heart rate was calculated from the continuous E.C.G. recording with a one-channel E.C.G. apparatus (type Cardiostat, Siemens, West-Germany). Directly after the exercise was finished the speed and gradient

Table 2. Reasons for not participating in the study.

Age	No reason	No interest	No time, school/ work	Afraid to participate	Did not want to be "guinea pig"	Total
4	2	-	-	4	5	11
6	5	1	1	4	-	11
8	4	1	1	5	-	11
10	4	3	1	3	1	12
12	4	2	3	4	-	13
14	2	3	-	3	-	8
16	1	5	1	4	-	11
18	3	2	8	-	-	13
Total	25	17	15	27	6	90

Table 3. Medical reasons for exclusion from the tests.

Mental retardation	5
Physically handicapped	3
Congenital heart disease	1
Fracture/meniscus	3
Astma	2
Muscular dystrophy	1
Obesity	1
Pregnancy	1

Table 4. Comparison of the Quetelet Index ($kg.m^{-2}$) of the participants and the personally approached negative response group (see Table 1).

	Age		Participants		Neg. response group (call/visit)	
	yrs.	n	mean	S.D.	n	mean
Boys	4	3	16.3	± 0.3	1	16.6
	6	7	15.8	± 1.6	2	14.8
	8	7	16.3	± 1.5	2	14.7
	10	8	16.9	± 1.4	3	16.5
	12	6	16.3	± 1.7	3	18.3
	14	11	18.6	± 2.0	-	----
	16	10	19.9	± 1.9	2	18.3
	18	9	20.2	± 1.2	3	19.8
Girls	4	6	15.6	± 1.3	2	14.8
	6	7	15.6	± 1.8	-	----
	8	11	16.6	± 1.7	1	16.3
	10	5	16.7	± 2.3	1	16.3
	12	10	18.4	± 2.5	1	18.1
	14	11	19.8	± 1.7	-	----
	16	9	19.9	± 3.4	3	18.3
	18	10	19.5	± 2.0	-	----

Table 5. Bruce treadmill test.

Stage	Time min	Speed $km.hr^{-1}$	Grade %	Equivalent Bicycle Ergometer loads $watt.kg^{-1}$
1	3	2.7	10	1.2
2	3	4.0	12	1.8
3	3	5.4	14	2.7
4	3	6.7	16	3.5
5	3	8.0	18	4.3
6	3	8.8	20	5.0
7	3	9.6	22	5.7

of the treadmill were reset at the first workload level, so that the subject had the opportunity to walk quietly for 5 to 10 minutes to recover. A blood sample was taken from the finger-pulp during the third minute of the recovery phase in order to determine the lactate concentration with a Boehringer-Mannheim enzymatic method (Hohorst, 1965).

The criteria for reaching maximal exercise were the leveling off of the heart rate despite an increasing workload during the test, and the appearance of an extreme forced ventilation. Subsequently, data were excluded from the results for children with a maximal heart rate lower than the mean max. H.R. minus two times the standard deviation, as given by Åstrand (1952) for the corresponding age. Data of children with a maximal respiratory exchange ratio (R) lower than 1.1 were also excluded. The R-limit for the 4-year-olds was set at 1.0 because most of the children did not reach the 1.1 R-level. In total, data of 35 children equally spread over the ages and both sexes were excluded.

Data for maximal H.R., R and blood lactate are also shown in Table 7 as supporting criteria for the evaluation of the maximal oxygen consumption data, as suggested by Åstrand (1952).

RESULTS

The mean ± S.D. for the different antropometric measurements for boys and girls of the different ages is shown in Table 6. Figures 1A and 1B respectively give the average height and weight for girls and boys compared to the Dutch standard growth tables of 1965 (van Wieringen et al., 1971). The boys as well as the girls are representative samples in this respect, taking into account a secular trend in height as stated by Roede (1981).

To compare the body composition of this group to other groups in The Netherlands, the mean sum of the 4 skinfolds of this study and the results of Haar et al. (1978) with younger children and Luyken et al. (1977) with adolescents are shown in Figures 2A and 2B. As can be seen, the results of our children are similar to these studies.

An evaluation of body composition was also desirable for making a comparison with the earlier studies, as mentioned before. Only the average weight of each age group was known from the study by Bink and Wafelbakker (1968)

Table 6. Antropometric data (mean ± S.D.) of boys and girls of different age groups

	n	Age (yrs.)	Height (cm)	Weight (kg)	Sum 4 skinfolds (mm)	Body fat (%)
Boys	3	4	105.3 ± 2.5	18.1 ± 1.0	30.1 ± 7.2	12.6 ± 2.8
	7	6	119.6 ± 4.7	22.7 ± 3.6	23.6 ± 6.1	9.6 ± 3.2
	7	8	130.0 ± 5.3	27.6 ± 3.6	23.2 ± 5.4	9.5 ± 2.5
	8	10	140.7 ± 6.8	33.4 ± 3.5	30.8 ± 5.1	12.0 ± 5.4
	6	12	146.8 ± 3.3	35.4 ± 5.1	26.4 ± 7.7	10.9 ± 3.4
	11	14	165.7 ± 9.1	51.3 ± 8.2	33.1 ± 13.6	13.3 ± 4.1
	10	16	178.6 ± 4.9	63.4 ± 6.7	31.4 ± 7.6	13.7 ± 3.9
	9	18	182.0 ± 5.7	67.0 ± 6.0	28.7 ± 8.9	11.7 ± 3.8
Girls	6	4	107.0 ± 4.6	17.9 ± 2.6	29.3 ± 5.7	18.9 ± 2.8
	7	6	119.1 ± 4.1	22.2 ± 3.5	25.9 ± 6.7	17.1 ± 3.1
	11	8	131.5 ± 4.7	28.9 ± 4.0	36.1 ± 15.7	20.9 ± 5.6
	5	10	140.1 ± 4.0	32.7 ± 3.7	31.1 ± 9.5	19.4 ± 4.4
	10	12	153.8 ± 7.2	43.9 ± 8.4	39.1 ± 16.4	20.8 ± 7.2
	11	14	163.4 ± 7.1	53.2 ± 8.5	46.4 ± 14.7	24.3 ± 5.5
	9	16	167.9 ± 5.4	55.9 ± 8.6	48.3 ± 15.0	24.6 ± 6.4
	10	18	166.5 ± 3.9	54.2 ± 6.1	44.8 ± 11.6	24.5 ± 3.7

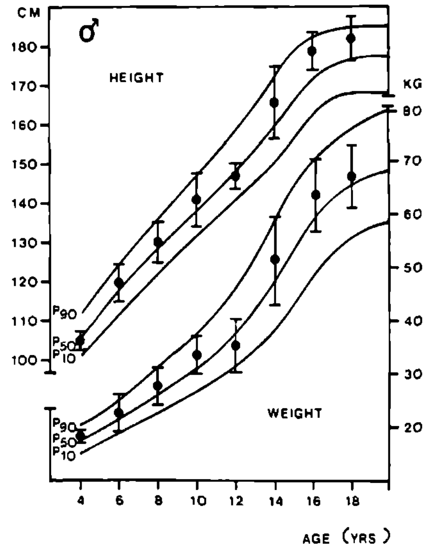

Figure 1A

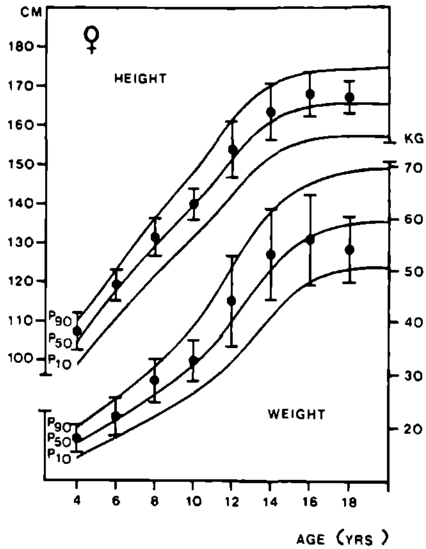

Figure 1B.

Figure 1A. *The mean values (± S.D.) of body weight and height of boys of the different age groups compared with the normal standards for Dutch boys (P10, P50 and P90: 10th, 50th and 90th percentile respectively) (van Wieringen et al., 1965).*

Figure 1B. *See Figure 1A, for girls.*

so that, although these are comparable with the present data on the weight of boys, no definite statement can be made with respect to the body composition. Furthermore, no skinfolds were measured in the study of Robinson (1938) and Åstrand (1952); so that a comparison is possible only on the basis of the quetelet index (Q.I. = weight (kg) . height^{-2} (m)). Keys et al. (1972) and others have shown that the Q.I. correlates well with the percentage of fat. It can be seen in the Figures 3A and 3B that, with the exception of the 18-year-olds in the study by Seliger and Bartůněk, the data of Åstrand, Robinson and Seliger and Bartůněk, lie within

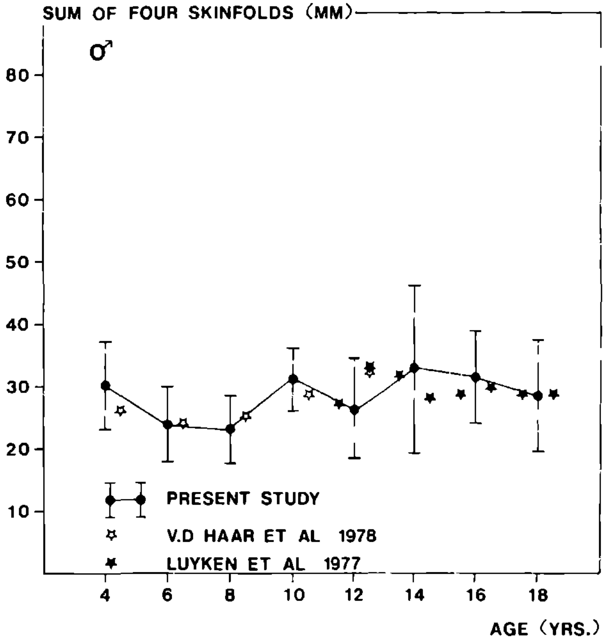

Figure 2A.

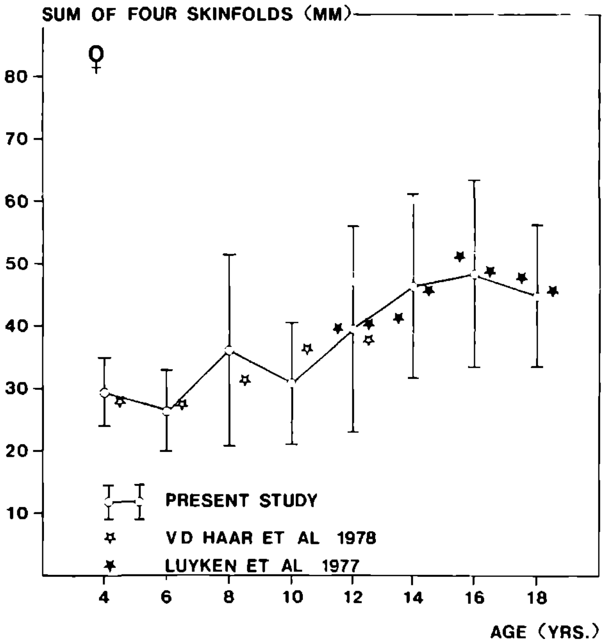

Figure 2B.

Figure 2A. *The mean values (± S.D.) of the sum of four skinfolds of boys for the different age groups compared with data of Dutch boys from v.d. Haar and Kromhout (1978) and Luyken et al. (1977).*

Figure 2B. *See Figure 2A, for girls.*

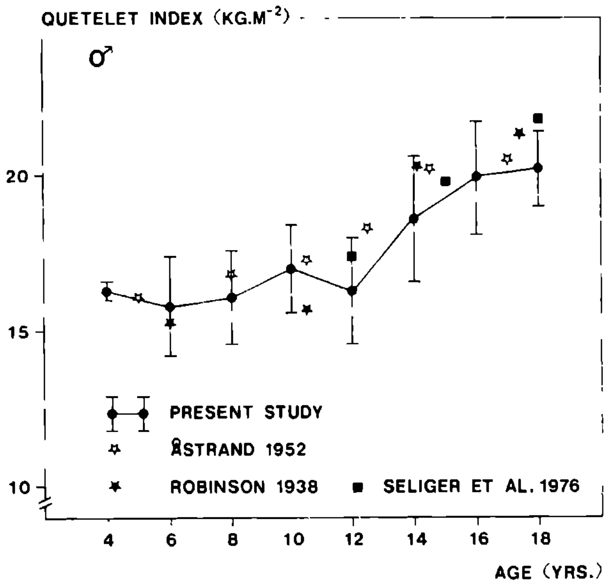

Figure 3A. *The mean values (± S.D.) of the Quetelet-index (kg.m^{-2}) of boys of the different age groups compared with the data from Robinson (1938, U.S.A.), Åstrand (1952, Sweden) and Seliger and Bartuněk (1976, Czechoslovakia).*

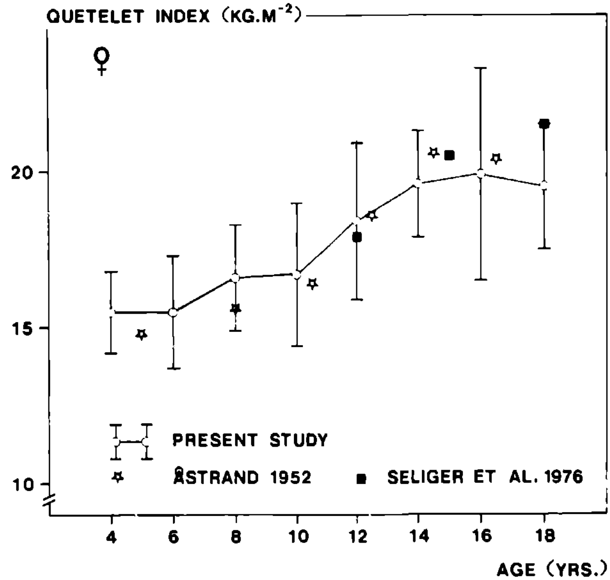

Figure 3B. The mean values (± S.D.) of the Quetelet-index (kg.m^{-2}) of girls of the different age groups compared with the data from Åstrand (1952, Sweden) and Seliger and Bartůněk (1976, Czechoslovakia).

1 x S.D. of our mean values indicating that there are no large differences.

The data concerning the aerobic power on the treadmill are shown in Table 7 for both sexes in each age group. Furthermore, the data from the maximal H.R., ventilation per minute, R and lactate concentration are included in order to give an impression of the level of maximal exercise. The number of children in the youngest age groups is small, because 29 % of the children were excluded on basis of the maximal criteria. The number of children who did not want to co-operate during the tests was also somewhat higher in this group (see Table 1: refusals during tests). The 4-year-olds had trouble keeping the mouthpiece in place to collect the expired air. The aerobic power, expressed in $\dot{V}_{O_2}$ max. per kg, increases for boys up to

Table 7. Aerobic power (mean ± S.D.) and related data of boys and girls measured with the Bruce treadmill protocol.

	n	Age (yrs.)	$\dot{V}_{O_2}$ max. ($l.min^{-1}$)	$\dot{V}_{O_2}$ max. ($ml.kg^{-1}min^{-1}$)	$\dot{V}_E$ max. ($l.min^{-1}$)	H.R. max. ($beats.min^{-1}$)	R	Lactate ($mmol.l^{-1}$)
Boys	3	4	0.73 ± 0.14	40.4 ± 5.3	32.7 ± 2.5	206 ± 12.0	1.10 ± 0.08	5.2 ± 0.6
	7	6	1.06 ± 0.16	47.0 ± 6.0	47.7 ± 6.3	203 ± 6.0	1.20 ± 0.07	7.2 ± 2.1
	7	8	1.46 ± 0.17	53.0 ± 3.6	60.0 ± 7.3	207 ± 9.9	1.18 ± 0.07	7.0 ± 1.7
	8	10	1.76 ± 0.23	52.7 ± 5.5	74.8 ± 9.9	205 ± 6.1	1.20 ± 0.04	8.3 ± 0.9
	6	12	1.88 ± 0.33	53.0 ± 4.7	70.7 ± 8.0	206 ± 5.1	1.19 ± 0.11	8.2 ± 1.9
	11	14	2.62 ± 0.49	51.1 ± 5.1	92.6 ± 21.2	203 ± 7.5	1.19 ± 0.07	9.7 ± 1.7
	10	16	3.48 ± 0.44	55.1 ± 6.0	120.3 ± 16.6	202 ± 6.9	1.21 ± 0.05	10.9 ± 1.5
	9	18	3.46 ± 0.37	51.7 ± 3.8	112.0 ± 10.8	198 ± 6.3	1.21 ± 0.04	10.2 ± 2.4
Girls	6	4	0.68 ± 0.18	38.0 ± 7.8	32.0 ± 9.3	209 ± 2.6	1.16 ± 0.06	6.0 ± 1.5
	7	6	1.05 ± 0.16	47.2 ± 3.5	43.0 ± 5.7	205 ± 6.4	1.19 ± 0.09	7.8 ± 2.1
	11	8	1.22 ± 0.17	43.0 ± 4.6	53.3 ± 6.2	203 ± 4.0	1.23 ± 0.06	8.1 ± 2.1
	5	10	1.52 ± 0.09	46.8 ± 4.5	61.0 ± 5.4	205 ± 6.0	1.27 ± 0.05	9.7 ± 2.2
	10	12	2.01 ± 0.25	46.5 ± 5.7	75.4 ± 9.9	208 ± 6.8	1.22 ± 0.04	9.3 ± 1.7
	11	14	2.36 ± 0.42	44.6 ± 4.7	87.6 ± 17.1	200 ± 6.4	1.21 ± 0.07	10.2 ± 1.9
	9	16	2.37 ± 0.31	42.6 ± 4.3	86.3 ± 13.0	196 ± 7.1	1.22 ± 0.07	10.7 ± 3.2
	10	18	2.25 ± 0.31	41.6 ± 5.3	83.8 ± 10.5	200 ± 6.3	1.23 ± 0.05	10.7 ± 2.3

the age of 8 years and then remains constant with a somewhat higher value for the 16-year-olds. The aerobic power per kg body weight for girls is fairly constant from 6 years on and begins to decrease somewhat at about 14 years of age.

To compare the aerobic power of this group of children compared with earlier studies, the mean $\dot{V}_{O_2}$ max. per kg (± S.D.) of this and other studies are plotted in Figures 4 A and 4B.

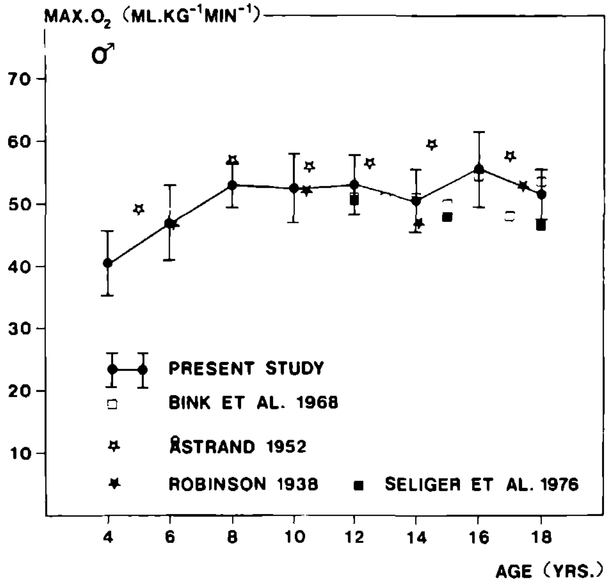

Figure 4A. *The mean values (± S.D.) of maximal oxygen consumption per kg body weight of boys of the different age groups compared with the data from Robinson (1938, U.S.A., treadmill), Åstrand (1952, Sweden, treadmill), Bink and Wafelbakker (1968, bicycle ergometer) and Seliger and Bartůněk (1976, Czechoslovakia, bicycle ergometer).*

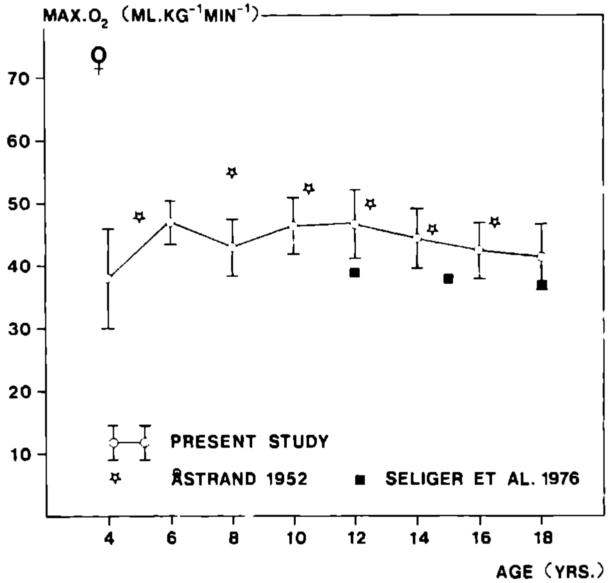

Figure 4B. The mean values (± S.D.) of maximal oxygen consumption per kg body weight of girls of the different age groups compared with the data from Åstrand (1952, Sweden, treadmill) and Seliger and Bartůněk (1976, Czechoslovakia, bicycle ergometer).

The studies by Bink and Wafelbakker (1968) and by Seliger and Bartůněk (1976) made use of the bicycle ergometer. It is generally assumed that the treadmill gives about 7.5-10 % higher values than the bicycle ergometer (W.H.O., 1968). When these differences are taken into consideration, it becomes clear that the values of the present study are lower than those of Bink and Wafelbakker and Åstrand (approximately 0-5 % lower) and agree quite well with those of Robinson and Seliger and Bartůněk.

DISCUSSION

Selection of the Children

Selecting groups of children for the purpose of collecting reference values with respect to physiological exercise parameters is a difficult task. Studying large numbers is prohibitive due to the very time-consuming character of this type of work. Furthermore, co-operation of the subjects is a very important factor. It can be expected that physically fit subjects will have a greater tendency to co-operate than those who have a poor physical condition.

The selection methods which up to now have been applied to this type of research with children were based on school samples. The advantage of this method is the general stimulating effect the children give one another through exchange of experiences. Furthermore, the minority does not want to remain behind when the majority participates. The disadvantage of this method is the problem of making a representative selection of schools in the chosen area, particularly because the children over 16 years of age are no longer obligated to go to school.

A different, more elegant method is to select a random sample in the city area. The disadvantage of this is that the exchange of experiences among the subjects and the stimulation to participate will hardly occur or not at all. Another disadvantage is the fact that then the study cannot take place in the familiar environment of the school and it is necessary to convince the child that the study has nothing to do with the hospital, a factor which can also cause the parents to be initially unenthousiastic about the research.

However, it is of great importance for this study that the sample is representative since the data are meant to be used as reference values, for example in the clinic. If we want to speak of a representative sample, then information about the reasons for non-participation is essential because of the possible negative attitude towards this study especially in the group of children with a poorer PPC.

From Table 1 it seems that there is no separate age/sex pattern with respect to non-participation in the study. The number of younger children that moved was greater in view of the fact that young families were involved.

Of special importance was the group that did not respond after 2 letters. It can be expected that especially this group contains children who did not participate because of a low PPC. To obtain more information about this, the quetelet index (Q.I.) was calculated for this group in Table 4. The literature shows that there is a close relationship between the percentage fat, physical activity and the PPC of children. Fat children are generally less active than thinner children. They have a higher Q.I. and a lower PPC (Montoye, 1975; Saris et al., 1980). The Q.I. is therefore used as indicator for the PPC. The Q.I. values of the children participating gave no response were equal to the Q.I. values of the children participating in the study (Table 4). On the basis of the Q.I. values, it is assumed with the necessary caution that no clear selection has occured, in the sense of a lower participation of children with a lower PPC. In Table 2, the high percentage of "no reason" or "no interest" was evident: no attempt was made to determine the extent to which these reasons for not participating came from a group of children with a low PPC. Furthermore, there was a remarkably large number of children who did not want to take free from school or work to participate in this study.

In summary, it is carefully concluded that, although the information is limited, there are no indications that the children who did not participate have a lower PPC than the participating children. The percentage of children participating in this study (65 %) seems satisfactory to us. Till now only Seliger and Bartiněk (1976) have published a study about the physical fitness of a randomly selected group. However, no information was given about the non-response.

The Bruce Treadmill Test

The treadmill test is generally accepted as the best method for children below the age of 10 years (W.H.O., 1968), especially because small children have difficulties maintaining a certain pedalling frequency on the bicycle ergometer. Various workload protocols have been published. Most of these are based on a constant speed and an increasing gradient (Skinner et al., 1971; Kemper, 1981). The disadvantage of such a design is the fact that the constant speed cannot always be applied to subjects of all age groups. This makes the procedure all the more complicated, making the method less attractive for routine use. To avoid this, the Bruce test was chosen, in which the speed as well as the gradient are increased every 3 minutes (see Table 4). Furthermore, the Bruce test has been used with positive experience with young children which cannot be said of other tests (Cummings et al., 1978). Moreover, it appears from the first study with 9-year-old boys (Saris et al., 1981 A) that the test was easily performed.

However, the test also had disadvantages. Especially the change of speed gave some subjects problems with maintaining the correct walking or running rhythm, which can affect the length of the test with the possible result that the maximal oxygen consumption is not reached. Cummings et al. (1978) also describes this.

Comparison with Previous Studies

Through technological developments since the 30's and 40's, it is reasonable to assume that the amount and intensity of the physical activity of adults has fallen to a lower level. It is less reasonable to assume this for children because they are more spontaneous by nature and are more independent of technical equipment. A historical comparison of the degree of physical activity is not possible because such information has become available only in recent years. Åstrand et al. (1963) and Ekblom (1971) and others indicate that inactive children have 5 to 15 % lower aerobic power than active children. Because data concerning aerobic power already were published in the 30's (Robinson, 1938), a comparison can be made on this basis.

It appears that the only cross-sectional research performed in the past in The Netherlands is that of Bink and Wafelbakker (1968). The only randomly selected study about the PPC in children was performed in Czechoslovakia by Seliger and Bartůněk (1976).

Data of that study and the research by Åstrand in Stockholm in the period from 1947 to 1951 and by Robinson in Boston in 1938 are the most suitable earlier data with which to compare our findings. It is shown in the section on results that our data are about 0-5 % lower than those of Bink and Wafelbakker and Åstrand.

Which factors could play a role in the differences between the data from our study and that of other studies? Possibly, the most important point of difference between the studies is the selection of the subjects. From the publication of Bink and Wafelbakker (1968), as in the publications of Åstrand, it is suggested that the sample is not representative for the respective age groups because the "poorly" performing subjects were not prepared to participate. This is less clear in the study of Robinson. The 6-year-olds were healthy middle class boys living at home. Unfortunately, no mention was made of the reasons why no maximal values were given for 50 % of this young group. The 10-year-olds came from an orphanage, while the 14- and 17-year-olds were students in a private school. The selection procedure in the study of Seliger and Bartůněk was the same as in our study.

Another possible factor which could explain the noted differences in aerobic power is the difference in test procedures. Besides the described differences between the treadmill and bicycle ergometer results there are also differences within the treadmill procedures. In the study by Åstrand the children walked several times in a period of 3 weeks and therefore had time to get used to the procedure. In the other studies the measurements were completed in one day. Furthermore, the increasing workloads of the Bruce test (compare the equivalent bicycle ergometer loads in Table 5) may be too high for the younger age groups. Therefore, anaerobic metabolism may be important and consequently force the child to stop before the maximal oxygen consumption is reached due to muscle ache. Comparative research with other test procedures is necessary to throw some light on this matter.

Along with the above findings, and assuming that the aerobic power of the youth in The Netherlands was at the same level as 15 to 40 years ago comparable with that of the youth in Czechoslovakia around 1968, and in Sweden around 1950, and in the U.S.A. around 1940, it is carefully concluded that since that time no clear decline has occurred in the aerobic power of young Dutch people from 4 to 18 years of age. If we include the data of Bink and Wafelbakker (1968) of 15 years ago and that of Kemper et al. (1981), (13-14-year-old boys, mean intake 59 $ml.kg^{-1}min^{-1}$; girls, 51 $ml.kg^{-1}min^{-1}$), Saris et al. (1981 A), (9-year-old boys, mean intake 55 $ml.kg^{-1}min^{-1}$) and Saris et al. (1981 C), (10-year-old boys, mean intake 59 $ml.kg^{-1}min^{-1}$; girls, 52 $ml.kg^{-1}min^{-1}$) with selected groups of children, then this conclusion seems reasonable, since these values are rather high. This might indicate that despite various negative pronouncements (Commission "Bewegings armoedig onderwijs", 1980) the physical activity of Dutch children is sufficient to maintain a good level of aerobic power.

In another way this impression is supported by the observation, described by various investigators (Lange Andersen et al., 1978; Gilliam et al., 1980; Yoshida et al., 1981), that extra physical training does not result in an improvement in aerobic power of young children. This could also mean that the general level of physical activity is so high that a decline in physical activity may affect the aerobic power only after a number of years. Therefore, health education and more in particular physical education should be directed towards the enjoyment of the activity itself and the accompanying aspects such as being outdoors, social contacts, the feeling of fatigue afterwards etc. If physical activities are enjoyed, some children will probably continue to be active and benefit from the physical and psychological advantages in later years.

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AEROBIC POWER, DAILY PHYSICAL ACTIVITY AND SOME CARDIO-VASCULAR DISEASE RISK INDICATORS IN CHILDREN AGES 6 - 10 YEARS

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(Amer.J.clin.Nutr.: submitted)

SUMMARY

A study was conducted to determine the levels of physical performance capacity (PPC), daily physical activity and some arteriosclerosis risk factors in about 800 children, ages 6, 8 and 10 years.

Aerobic power ($\dot{V}_{O_2}$ max.) was measured on the treadmill. Daily energy expenditure (T.E.E.) was estimated from 24-hour heart rate (H.R.) recording and the individual relationship between H.R. and energy expenditure (E.E.). The E.E. spent above 50 and 75 percent of the individual $\dot{V}_{O_2}$ max. (E.E. >50 and E.E. >75) was also calculated. In addition to these parameters data were collected about the body fatness, bloodlipids and nutrient intake using the 24-hour recall method.

Boys and girls were grouped for analysis into a low $\dot{V}_{O_2}$ max. group, a middle group and a high $\dot{V}_{O_2}$ max. group. Boys had a significantly higher $\dot{V}_{O_2}$ max., a lower body fat, a higher HDL/total cholesterol ratio, a higher T.E.E., E.E. >50 and E.E. >75 and a higher nutritional intake at all ages. No clear difference was found between the high and low $\dot{V}_{O_2}$ max. groups in T.E.E., E.E. >75, energy and nutritional intake in all age groups of boys and girls. However, the high aerobic power groups had significantly lower 24-hour mean H.R., E.E. >50, % body fat and a higher HDL/total cholesterol ratio.

The energy and nutrient intake results suggest that specific dietary factors are less important determinants of the level of aerobic power.

In general it is concluded that children at this age with different levels of aerobic power do not differ substantially in their daily physical activity. Furthermore, a relationship was noted between the level of aerobic

power, body fatness and bloodlipids. Children with a high aerobic power are leaner and have a higher HDL/total cholesterol ratio.

Key words: Aerobic power - Daily physical activity - Body composition - Bloodlipids - Nutrition - Children.

INTRODUCTION

In the field of primary prevention there is an increasing interest in the relation between physical fitness, daily physical activity and general health and more specificly the prevention of cardio-vascular diseases (C.V.D.). The results of longitudinal population studies indicate that physical activity can be regarded as a protective factor against C.V.D. (Froelicher and Oberman, 1972).

Althought C.V.D. first becomes apparent at middle age or later adulthood, it is now clear that a certain level of risk can be identified during childhood. That is why the World Health Organisation recommends that preventive measures should be started at childhood (W.H.O., 1974).

Several large-scale studies were performed with children to identify the level of the risk indicators. Most of these studies did not, however, include physical fitness and daily physical activity measurements. In the present study, data are given for the level of aerobic power, as representative for physical performance capacity (PPC), the daily physical activity and risk indicators such as obesity, bloodlipids and nutritional habits of a normal, healthy population of schoolchildren. This study is part of a health education study (the G.V.O.-project).

METHODS

Population

The G.V.O. - health education project - is a large-scale study to develop a school health education program called "To Your Health" for kindergarten and primary schools. To evaluate the effects of this program, a controlled study was started in 1976 in 30 kindergarten schools (15 experimental and 15 control) in the Nijmegen area (population 200.000). About 800 children participate in the study at the moment. The scope, purpose and requirements of the project were explained to the respective school boards and parents and an informed consent was obtained. The first evaluative study early in the project was made in 1977 (age of the children 6 years). The results of the evaluation after 1 and 3 years of health education showed no differences between experimental and control groups for any of the variables used in this study. Therefore, the combined data of experimental and control groups will be presented here. The children represented high, middle and low social classes and were in good general health.

Body Composition

Body weight, height and the thickness of four skinfolds (biceps, triceps, subscapular and crista iliaca) were measured. The skinfold measurements were taken with a Holtain calipper (Holtain LTD, Crosswell, U.K.). Percentage of fat was determined using the Durnin and Womersly tables (1974).

Aerobic Power

The aerobic power was measured on a Quinton (U.S.A.) treadmill at the schools. The 6-year-old children walked at a constant speed of 4.0 $km.hr^{-1}$. The 8- and 10-year-old children walked at a speed of 4.5 $km.hr^{-1}$. Every two minutes the slope was increased with a 5 % gradient starting horizontally. The test period ended when a heart rate of about 170-180 $beats.min^{-1}$ was reached.

Oxygen consumption ($\dot{V}_{O_2}$) was obtained by means of the Douglas-bag technique. Expired air was collected during the second minute of the workload at gradients 5 %, 10 % and 15 % or, if the physical fitness was low at 0 %, 5 % and 10 %. The E.C.G. was recorded continuously and the heart rate (H.R.) was calculated during the air collection period. The collected volume of expired air was measured by means of a dry-gasmeter (Dort, The Netherlands) and the gasanalysis was made with an O_2-paramagnetic analyzer (Servomex, Taylor, England). No CO_2-gasanalysis was made which can lead to an error in the calculated oxygen consumption of -4 % to +2 % in the R-range of 0.8 to 1.1 (Croonen and Binkhorst, 1974). During the last measurement, when the children were 10 years old, an automatic ergo-analyzer (Oxycon-4, Mijnhardt, The Netherlands) was used instead of the Douglas-bag method. This analyzer was checked regularly during the experimental period with the Douglas-bag method and showed very good agreement. The maximal oxygen uptake or aerobic power was calculated from the individual regression equation, based on the three measurements on the treadmill, using a maximal heart rate (H.R.) for the three age groups, 6, 8 and 10 years of 213, 210 and 208 beats.min^{-1} respectively. These mean values were found during direct measurements of the aerobic power for a group of 9-year-old (n=41) and 10-year-old (n=153) children. The mean value given by Åstrand and Rodahl (1977) was used for the 6-year-olds.

Daily Physical Activity

Physical activity (P.A.) was expressed as the energy expenditure (E.E.) estimated from the 24-hour H.R. recording during a normal school day. P.A. was also estimated with a questionnaire given to the teacher.

An 8-level H.R. integrator as described by Saris et al. (1977 A) was used for the H.R. recordings. In essence, each R-R interval is transformed into an H.R. and stored in the appropriate register for H.R. ranges of 40-69, 70-99, 100-124, 125-149, 150-176, 177-199 and 200-224 beats.min^{-1}. To calculate the mean time spent in each of the 7 H.R. registers during the 24-hour period the number of counts in a certain register was divided by the mean H.R. of the register; except for registers 1 and 2 in which a heart rate of 55 and 82.5 was used for the age groups of 6 and 8 years. A mean heart rate of 60 was used for the 10-year-old age group for register 1 because an H.R. of 55 was no longer a good estimation of the mean H.R. This procedure has shown to be valid in a pilot study (Saris et al., 1977 B).

E.E. during the school day was calculated from the measured H.R. and the calculated individual regression line between H.R. and E.E.min^{-1} (measured during 5 minutes standing and three levels of treadmill exercise). E.E.min^{-1} obtained in this way is converted into total E.E. per day (T.E.E.) using the time per H.R. level obtained as described above.

This method however should be explained in somewhat more detail. At the transition from more restful activities such as lying, sitting and standing to moderate exercise such as walking and cycling a change in the relationship between H.R. and E.E. can be found (see also Åstrand and Rodahl, 1977; Dauncey and James, 1980). We found in general this change to be between 110-125 beats.min^{-1} for young children. The individual E.E. per min^{-1} of standing was therefore used for H.R. levels below 125 beats.min^{-1}. For the periods spent with an H.R. higher than 125 beats.min^{-1}, E.E.min^{-1} was calculated using the measured H.R. of the respective register and the individual regression equation between H.R. and E.E.min^{-1}. The total E.E. per H.R. register was calculated by multiplying E.E.min^{-1} by the time spent in the different H.R. registers. In this way it was possible to calculate the T.E.E. by summation of the E.E.'s per register. Furthermore, it was possible to calculate the 50 % and 75 % level of that aerobic power from the individual regression equation based on the three treadmill workloads and the aerobic power. The corresponding H.R. points at these two E.E. levels were rounded off to the nearest lowest or highest level of the respective frequency registers of the H.R. recorder. It was possible to establish the time spent at a level of aerobic power higher than 50 % and 75 % respectively, from the time spent in each of the H.R. registers and these two rounded off H.R. points. It was also possible, as described above, to calculate the E.E. spent above 50 % and 75 % of the individual maximal aerobic power (E.E. >50 and E.E. >75 respectively). The E.E. >50 and E.E. >75 were used as indicators for more intense activities.

The level of P.A. was furthermore obtained from an 8-item questionnaire given to the teacher. The items, such as P.A. during playing hours, were rated on a 5-point scale. The P.A. was calculated from this questionnaire in a percentage: a score of 100 % corresponded with a maximum score of 8 x 5 points (i.e. 100 % active).

Bloodlipids

A venous bloodsample was taken between 10 a.m. and 12 a.m. in a nonfasting state. From a study with a small subsample of the children it was concluded that after 10 a.m. the post-prandial effect on the breakfast on the total cholesterol level was minimal (Saris, 1973).

Serum cholesterol was measured with Liebermann-Burchardt reagent using serum calibrators calibrated according to Abell et al. (1952) at the Human Nutrition Laboratory in Wageningen. The lipid laboratory is certified by the Center for Disease Control, Atlanta, G.A., U.S.A., as meeting the W.H.O. criteria. Reproducibility for blind control sera provided by the Center for Disease Control was about 1 % (coefficient of variation) and the absolute level was in general within 1 % of the "true" (target) values (Katan et al., 1982).

HDL cholesterol was determined after manganese-heparin precipitation of apo-B containing lipoproteins (Burnstein and Samaille, 1960) as previously described (v.d. Haar et al., 1978). For blind control sera obtained in the Center for Disease Control Survey of HDL cholesterol Measurement a reproducibility of 2.2 % (coefficient of variation) was found.

Food Intake

The 24-hour recall method was used to record energy intake (E.I.) and dietary composition. Specially trained dietitians visited the families at home. Complete descriptions of each food item consumed during the previous 24 hours were recorded on standard forms. A parent gave the information for the younger children. In the older age groups, the child was also involved in the interview. Methods of preparation, type of fat used in cooking, brand names etc. were recorded. Food models and photo's were used to quantitate the food items. The dietary recalls were obtained on every school day except Friday.

The nutritional composition of the food intake was calculated using the uniform Dutch coding book based on the Dutch food composition table (Commission U.C.V., 1975). After coding, the data underwent an error checking procedure (Elvers, 1980)

Statistical Methods

Summary statistics for the different parameters were calculated for age and sex. The children were ranked according to a low (<25th percentile), intermediate (25th-75th percentile) or high (>75th percentile) level of aerobic power. The significance of the different mean values of the lowest and highest percentile group was tested with the student's *t*-test.

RESULTS

Sex-Age Differences

In Table 1 the mean (± S.D.) data about physical characteristics and daily physical activity are given for boys and girls for the different age groups. All data showed significant differences between boys and girls except for height and weight for the 10-year-olds. The girls had a higher mean sum of four skinfolds for all three age groups. The aerobic power expressed in $\dot{V}_{O_2}$ max. per kg body weight and per kg.LBM was higher in boys in all age groups. The value increased with age in boys, while in girls it remained constant.

Indices of daily physical activity (T.E.E., E.E. >50, E.E. >75 and P.A.) were higher for the boys. On the other hand the 24-hour mean H.R. was higher for the girls. As expected, the T.E.E. increased with age for both boys and girls.

In Table 2 the mean (± S.D.) data of bloodlipids and nutritional intake are presented. Total cholesterol was significantly different between boys and girls and increased with age for both groups. Whereas the HDL cholesterol was the same in all age groups. The HDL/total ratio was significantly higher in boys.

The daily E.I. was significantly higher in boys than in girls in all age groups. The main contribution to the difference in E.I. between boys and girls came from the intake of carbohydrates. Furthermore, the fiber intake was higher in boys. A remarkable and unexpected finding was that the E.I. at the age of 10 was almost the same as that at the age of 8, for boys as well as for girls.

Aerobic Power and other Variables

The selected variables per group of aerobic power (per kg body weight) for boys can be found in Table 3a and 3b, only mean values are presented for the sake of a clear overview. Boys ages 8 and 10 years in the low quartile groups were taller, heavier and had a higher sum of four skinfolds than those in the high groups. There were no differences between the groups in T.E.E. and E.E. >75. The boys with a lower aerobic power however had a higher mean daily H.R.min^{-1} and E.E. >50. The P.A. revealed a higher score for the upper quartile group only in the 10-year-old group. The HDL/total cholesterol ratio was significantly higher for all the high quartile groups.

Table 1. Mean (± S.D.) antropometric, aerobic power and physical activity indices in relation to age and sex.

	6 years			8 years			10 years		
	Boys *n*=372	Girls *n*=339	p[a]	Boys *n*=427	Girls *n*=447	p[a]	Boys *n*=368	Girls *n*=426	p[a]
Body composition									
Age (yrs.)	6.1 ± 0.3	6.1 ± 0.3		8.1 ± 0.3	8.1 ± 0.3		10.2 ± 0.3	10.2 ± 0.4	
Height (cm)	118 ± 5	118 ± 5		131 ± 6	130 ± 6		142 ± 6	142 ± 7	
Weight (kg)	21.6 ± 3	21.2 ± 3	*	27.3 ± 4	26.4 ± 4	*	33.6 ± 6	33.5 ± 6	
Sum 4 skinfolds (mm)	22 ± 5	25 ± 6	***	22 ± 8	26 ± 8	***	24 ± 12	30 ± 12	***
Aerobic power									
$\dot{V}_{O_2}$ max.kg^{-1} (ml.kg.min^{-1})	55.3 ± 10	50.5 ± 9	***	57 1 ± 8	51.6 ± 8	***	59.0 ± 10	52.5 ± 9	***
$\dot{V}_{O_2}$ max.kg.LBM^{-1} (ml.kg.LBM.min^{-1})	64.2 ± 12	59.4 ± 10	***	66 0 ± 9	61.1 ± 9	***	68.5 ± 11	62.8 ± 10	***
Physical activity									
Mean H.R. per day (beats.min^{-1})	96.7 ± 7	98.6 ± 7	**	90 0 ± 7	92.8 ± 7	**	87.6 ± 8	89.2 ± 7	**
T.E.E. (kcal)	1760 ± 252	1613 ± 238	***	2024 ± 281	1826 ± 261	***	2251 ± 392	2008 ± 364	***
E.E. >50 (kcal)	333 ± 303	252 ± 246	*	311 ± 240	238 ± 210	**	361 ± 334	207 ± 232	***
E.E. >75 (kcal)	44 ± 50	25 ± 30	***	45 ± 44	28 ± 36	***	63 ± 71	25 ± 45	***
P.A. score (%)	63 ± 17	58 ± 16	***	59 ± 11	49 ± 11	***	60 ± 12	49 ± 11	***

[a]Student's *t*-test: *, $p<0.05$; **, $p<0.01$; ***, $p<0.001$.

Abbrevations: T.E.E.: Total Energy Exp. per day; E.E. >50: Energy Exp. above the 50 % level of the individual maximal aerobic power; E.E. >75: Energy Exp. above the 75 % level of the individual maximal aerobic power.

Table 2. Mean (± S.D.) blood lipids and selected dietary variables in relation to age and sex.

	6 years			8 years			10 years		
	Boys	Girls	p[a]	Boys	Girls	p[a]	Boys	Girls	p[a]
Bloodlipids									
Total cholesterol ($mmol.l^{-1}$)	4.2 ± 0.6	4.3 ± 0.7	*	4.3 ± 0.7	4.5 ± 0.7	**	4.4 ± 0.7	4.6 ± 0.7	**
HDL cholesterol ($mmol.l^{-1}$)	1.4 ± 0.3	1.4 ± 0.3		1.4 ± 0.3	1.4 ± 0.3		1.4 ± 0.3	1.4 ± 0.3	
HDL/Total Ratio	0.33 ± 0.04	0.32 ± 0.05	*	0.33 ± 0.05	0.32 ± 0.05	**	0.32 ± 0.06	0.30 ± 0.05	**
Nutrition									
Total kcal 24 hrs.	1777 ± 445	1615 ± 404	***	1985 ± 482	1808 ± 462	***	2007 ± 458	1760 ± 464	***
Protein (g)	58 ± 18	52 ± 16	**	69 ± 20	63 ± 18	*	70 ± 20	62 ± 19	**
Fat Total (g)	77 ± 27	72 ± 26	*	82 ± 30	76 ± 27	*	85 ± 29	74 ± 28	**
Sat. (g)	35 ± 13	33 ± 12		37 ± 14	35 ± 12		37 ± 13	34 ± 13	*
PUFA (g)	9 ± 5	8 ± 5		12 ± 7	11 ± 6		13 ± 7	11 ± 6	
P/S Ratio	0.26 ± 0.20	0.24 ± 0.20		0.32 ± 0.20	0.31 ± 0.20		0.35 ± 0.30	0.33 ± 0.30	*
Cholesterol (mg)	221 ± 143	207 ± 146		231 ± 149	220 ± 147		256 ± 188	233 ± 160	
CHO Total (g)	212 ± 54	189 ± 48	**	242 ± 63	218 ± 60	**	240 ± 61	210 ± 56	***
Simple (g)	120 ± 35	110 ± 35	*	130 ± 44	120 ± 40	*	129 ± 44	116 ± 37	*
Fiber (g)	18 ± 7	16 ± 6	*	21 ± 8	18 ± 7	*	21 ± 8	18 ± 7	*

[a]Student's *t*-test: *, $p<0.05$; **, $p<0.01$; ***, $p<0.001$.

Abbrevations: HDL chol.: High Density Lipoprotein chol.; Sat.: Saturated fatty acids; PUFA: Poly Unsaturated Fatty Acids; P/S Ratio: PUFA/Sat. Ratio; CHO: Carbohydrates.

Table 3a. Mean of aerobic power, antropometric and physical activity variables for boys in relation to age and $\dot{V}_{O_2}$ max.kg^{-1} level.

	6 years				8 years				10 years			
	$\dot{V}_{O_2}$ max.kg^{-1} percentile[b]											
	low	middle	high	p[a]	low	middle	high	p[a]	low	middle	high	p[a]
$\dot{V}_{O_2}$ max.kg^{-1}	44.8	53.8	69.3		47.6	56.5	67.7		46.5	58.7	72.9	
Aerobic power												
$\dot{V}_{O_2}$ max.kg.LBM^{-1}	52.2	62.3	80.1	***	56.1	65.2	77.4	***	55.9	67.5	83.3	***
Body composition												
Height	119	119	118		132	131	129	**	143	142	141	**
Weight	21.9	21.7	21.4		29.2	26.7	26.0	***	36.8	32.9	31.8	***
Sum 4 skinfolds	22.6	22.0	21.5		26.6	21.5	19.5	***	32.3	21.0	20.0	***
Physical activity												
Mean H.R.per day	98.3	97.5	94.2	**	90.0	90.2	89.1	*	89.9	87.4	85.8	***
T.E.E.	1723	1787	1743		2067	1985	2048		2240	2233	2293	
E.E. >50	385	349	247	**	369	310	255	**	465	387	366	**
E.E. >75	37	48	43		53	41	46		77	56	55	
P.A. score	64	61	67		59	60	61		56	61	63	***

[a] Student's *t*-test between the lowest and highest group: *, $p<0.05$; **, $p<0.01$; ***, $p<0.001$.

[b] Low: <25th percentile; middle: 25-75 percentile; high: >75th percentile.

For abbrevations and units see Table 1.

Table 3b. Mean of the bloodlipids and selected dietary variables for boys in relation to age and $\dot{V}_{O_2}$ max.kg^{-1} level.

	6 years				8 years				10 years			
	$\dot{V}_{O_2}$ max.kg^{-1} percentile[b]											
	low	middle	high	p[a]	low	middle	high	p[a]	low	middle	high	p[a]
Bloodlipids												
Total cholesterol	4.3	4.2	4.0	**	4.3	4.3	4.3		4.5	4.4	4.4	
HDL cholesterol	1.5	1.4	1.4		1.4	1.4	1.4		1.4	1.4	1.5	
HDL/Total Ratio	0.35	0.33	0.36	*	0.32	0.33	0.34	*	0.31	0.32	0.34	**
Nutrition												
Total kcal	1763	1828	1808		2007	1945	2019		1968	2021	2014	
Protein	58	58	58		70	67	72		69	71	71	
Fat Total	78	81	80		82	79	87		84	85	86	
Sat.	36	36	36		36	35	40		37	37	38	
PUFA	9	9	9		13	12	12		12	13	14	
P/S Ratio	0.25	0.25	0.25		0.36	0.34	0.30		0.32	0.35	0.37	
Cholesterol	221	226	221		214	218	252		256	262	245	
CHO Total	205	216	216		245	239	237		232	243	240	
Simple	117	122	123		131	127	126		128	131	126	
Fiber	17	18	18		21	21	21		20	22	21	

[a], [b]See legend Table 3a.

For abbrevations and units see Table 2.

Table 4a. Mean of aerobic power, antropometric and physical activity variables for girls in relation to age and $\dot{V}_{O_2}$ max.kg^{-1} level.

	6 years				8 years				10 years			
	$\dot{V}_{O_2}$ max.kg^{-1} percentile[b]											
	low	middle	high	p[a]	low	middle	high	p[a]	low	middle	high	p[a]
$\dot{V}_{O_2}$ max.kg^{-1}	40.5	49.5	62.5		43.4	50.4	62.2		41.8	51.3	65.1	
Aerobic power												
$\dot{V}_{O_2}$ max.kg.LBM^{-1}	48.5	58.5	73.1	***	52.1	59.7	72.6	***	51.6	61.4	76.3	***
Body composition												
Height	119	118	119		131	130	129		143	142	141	**
Weight	21.8	20.9	21.3		27.4	26.7	25.1	***	36.3	33.2	31.2	***
Sum 4 skinfolds	27	24	23	**	29	26	23	***	37	28	24	***
Physical activity												
Mean H.R.min^{-1}	100.8	98.8	96.0	**	94.4	92.9	90.8	**	90.9	89.2	87.6	***
T.E.E.	1654	1607	1584		1753	1835	1803		1984	2034	1977	
E.E. >50	401	244	128	***	337	225	155	***	251	194	170	**
E.E. >75	33	21	28		32	27	25		30	25	20	
P.A. score	55	58	57		46	49	51		46	49	54	***

[a], [b]See legend Table 3a.

For abbrevations and units see Table 1.

Table 4b. Mean of the bloodlipids and selected dietary variables for girls in relation to age and $\dot{V}_{O_2}$ max.kg^{-1} level.

	6 years				8 years				10 years			
	$\dot{V}_{O_2}$ max.kg^{-1} percentile[b]											
	low	middle	high	p[a]	low	middle	high	p[a]	low	middle	high	p[a]
Bloodlipids												
Total cholesterol	4.1	4.3	4.4	*	4.6	4.5	4.3	**	4.7	4.5	4.7	
HDL cholesterol	1.3	1.4	1.5	**	1.4	1.4	1.4		1.3	1.4	1.5	**
HDL/Total Ratio	0.32	0.33	0.34	**	0.30	0.31	0.33	**	0.28	0.31	0.32	***
Nutrition												
Total kcal	1702	1691	1566		1658	1840	1815	**	1762	1761	1760	
Protein	51	55	50		59	64	64		63	61	63	
Fat Total	72	76	71		70	79	74		76	74	73	
Sat.	34	34	32		32	36	33		34	34	33	
PUFA	8	10	9		10	11	10		11	10	11	
P/S Ratio	0.23	0.29	0.28		0.31	0.31	0.30		0.32	0.29	0.33	
Cholesterol	202	221	207		186	234	244	**	236	232	236	
CHO Total	211	195	183		195	219	223	***	206	212	212	
Simple	128	114	106	**	108	121	122	**	112	119	115	
Fiber	18	17	14	**	17	18	20	**	18	18	19	

[a], [b]See legend Table 3a.

For abbrevations and units see Table 2.

The mean quantities of E.I. and nutrients showed no differences for any of the groups.

The data for the girls are given in Table 4a and 4b. A similar pattern as for the boys was found for the mean values of lower and upper quartile groups for aerobic power, body composition, daily physical activity indices and bloodlipids. Food intake results revealed a higher E.I. due to a higher intake of CHO and a higher cholesterol and fiber intake in the upper quartile group at age 8. Furthermore, the intake of simple CHO and fiber was higher in the lower 6-year-old group.

Energy Expenditure and Energy Intake of the 10-Year-Old Children

The relatively low E.I. in the 10-year-old compared with 8-year-old children (Table 2) was examined and seems to be due to the incomplete recording of the food intake. To illustrate this, selected antropometric and E.E. and E.I. variables for the 10-year-old boys and girls were ranked according to the sum of four skinfold thicknesses as an indication of fatness (Table 5). The boys as well as the girls in the high skinfolds group weighed significantly more than subjects in the low group. Their body weight corrected for the percentage of fat (lean body mass: LBM) was also higher. Furthermore, T.E.E. and T.E.E. per kg body weight was significantly higher in the high quartile group. T.E.E. expressed in kcal per kg.LBM, however, was no longer significantly different between the high and low quartile groups. These findings could have been expected: fat and lean children have the same T.E.E. per kg.LBM. However, the E.I. gave opposite results than was expected from the difference in body composition and E.E. values. The upper quartile group of boys had a significantly lower total E.I. per kg as well as per kg.LBM. The same tendency was found for the girls. Therefore, it is reasonable to conclude that there was an incomplete recording of food intake for the 10-year-olds.

DISCUSSION

The aim of this study was to investigate the relationship between the level of physical fitness expressed as the level of aerobic power, daily

Table 5. Mean body composition, energy expenditure and energy intake for 10-year-old boys and girls in relation to skinfold thickness level.

	Sum skinfold thickness percentile[b]							
	Boys				Girls			
	low	middle	high	p[a]	low	middle	high	p[a]
Sum 4 skinfolds (mm)	15.7	20.2	38.6		18.6	26.4	46.9	
Body composition								
Weight (kg)	30.1	32.5	39.5	***	29.5	32.6	39.4	***
LBM (kg)	27.1	28.3	31.2	***	25.9	27.4	30.4	***
Energy expenditure per 24 hrs.								
T.E.E. (kcal)	2163	2216	2404	**	1916	1997	2118	***
T.E.E. per kg	72	68	61	**	65	61	54	***
T.E.E. per kg.LBM	80	78	77		74	73	70	
Energy intake per 24 hrs.								
Total kcal	2045	2030	1892	*	1792	1789	1686	
Total kcal per kg	68	62	48	***	61	55	43	***
Total kcal per kg.LBM	75	72	61	***	69	65	55	**

a, bSee legend Table 3a.

For abbrevations see Table 1.

physical activity expressed in energy expenditure and a few variables which are assumed to be indicators of risk for cardio-vascular disease (such as obesity, the level of bloodlipids, and unfavorable nutritional habits). The relationship between these risk factors and the aerobic power and/or physical activity of schoolage children has been only sporadically studied and, for the most part, confined to studies on the effect of physical exercise on HDL cholesterol levels (Gilliam et al., 1977; Välimäki et al., 1980).

An important reason for this lack of data was the necessity of using cumbersome equipment or activity questionnaires to gather information about physical activity. These methods are unsuitable for studying children.

It is possible to estimate daily energy expenditure (T.E.E.) through continuous registration of heart frequency (see section on methods). The validity of this procedure was tested by making a comparison with the measured E.E. (Dauncey and James, 1979; Saris et al., 1982). The results from these investigations showed that, although the method can lead to individual errors of 10 to 20 %, the mean value gave a good estimation of the actual energy expenditure. Although the method is unsuitable for the exercise physiologist, it is valuable for comparing the mean results of groups in large-scale studies.

Energy Expenditure and Recommended Dietary Allowences (RDA)

Recently Spady (1980) published results of a study about the E.E. of 8- to 11-year-old children, using the H.R. method. It can be concluded that the T.E.E. values for our boys are at about the same level as the RDA's of the Dutch and other available RDA's for energy intake, as summarized by Spady, though slightly lower (for example: The Netherlands, ages 7-10 years, 2200 kcal). In agreement with Spady, the T.E.E. values for our girls are lower than all recommended RDA's (for example: The Netherlands, ages 7-10 years, 2000 kcal). Besides higher levels of resting metabolism in boys than in girls, as shown by Spady, it seems to us that the difference between the P.A. of boys and girls is an important factor. We calculated the E.E. above the level of 50 % and 75 % of the individual aerobic power and used this as an index for the intensity of the daily P.A. The contribution of the E.E. >50 and E.E. >75 is less for girls than for boys (Table 1), suggesting that girls are less active, already at the age of 6 years. This finding is supported by the P.A. score given by the teacher (Table 1). A third factor which could contribute to the lower E.E. values in girls is a relatively higher percentage of body fat.

Aerobic Power

As shown by many researchers (see review in Åstrand and Rodahl, 1977) this study also shows that the absolute and relative aerobic power (per kg of body weight or, per kg.LBM, Table 1) is higher for boys than for girls.

The mean values for the aerobic power in our group are quite high compared to those in the literature (Table 1). Values of 48 to 60 $ml.kg^{-1}min^{-1}$ have been reported for boys and 35 to 52 $ml.kg^{-1}min^{-1}$ for girls (see review, Saris et al., 1982) . There are at least three possible explanations for these findings: the subjects gained experience with the procedure; the aerobic power was overestimated (see section on Methods); the subject feel comfortable since the measurements were taken at school. It is not possible to indicate which of the reasons is the most likely.

Bloodlipids

The mean serum total cholesterol levels found in this study agree with the values reported for Dutch boys (4.4 $mmol.l^{-1}$) and girls (4.6 $mmol.l^{-1}$) (v.d. Haar and Kromhout, 1978) and with some studies in America, for boys and girls 4.2 and 4.3 $mmol.l^{-1}$ respectively (Frerichs et al., 1976; Morrison et al., 1978). However, the levels are, lower than those found for Danish (Kaas Ibsen et al., 1980), median value for boys and girls 4.5 $mmol.l^{-1}$, and Finnish children, boys and girls 6.0 and 6.1 $mmol.l^{-1}$ respectively (Räsänen et al., 1978). In agreement with Mjøs et al. (1977) and the studies of Scrinavasan et al. (1976) and Morrison et al. (1978) the present results indicate that boys and girls at these ages have the same mean HDL cholesterol levels. The HDL/total ratio is significantly lower for girls (Table 2).

The Dietary Intake

One of the most widely used approaches for the collection of nutritional information is the 24-hour recall method. Many workers have dealt with the validity of the method. Beaton et al. (1979) concluded in their extensive study of adults that the 24-hour recall is suitable for the estimation of the mean energy intake.

An added problem with children is the changing knowledge of the food intake with increasing age. At 10 years of age it is apparent that the mother does not know everything about the food intake of the child. This is especially true for the betweenmeals, snacks and sweets. It is questionable whether the children can supplement this information. As was pointed out in the section Results it can be assumed that there was incomplete information about the E.I. of the fatter children. There is apparently a conscious or unconscious concealment of information about part of the food intake.

A decrease in the energy consumption between the ages of 10 and 13 years can also be seen in the data of Boulton (1981). One can also question whether all of the food was noted. Therefore, the dietary information for this age group must be interpreted very carefully.

In general the composition of the diets was not different from the composition of diets in comparable age groups in The Netherlands (v.d. Haar and Kromhout, 1978). The significantly different E.I. of girls and boys is a result of a higher intake of proteins, fat and especially carbohydrates by boys.

Aerobic Power and Daily Physical Activity

In earlier studies the mean daily H.R. was used as an indicator for the daily P.A. (Lange Andersen, 1967; Masironi and Mansourian, 1974; Saris et al., 1977 A; Gilliam et al., 1981). It was generally assumed that someone with a high mean daily H.R. was more active than someone with a low mean daily H.R. From Tables 3a and 4a, however, it can be seen that, in all age groups, children with a high aerobic power had a slightly, but significantly, lower mean H.R.

It is well-known that a better state of endurance fitness coincides with a lower mean H.R. during work (Åstrand and Rodahl, 1977). The results of this study suggest that a better physical fitness has a greater influence on the mean daily H.R. than does the level of daily physical activity.

Therefore no conclusion with regard to the level of daily physical activity can be drawn from the 24-hour H.R. results alone.

The analysis of the data related to levels of aerobic power reveals some interesting findings for boys as well as for girls (Tables 3a and 4a). No relation was found with the level of aerobic power in any of the age groups when the T.E.E. was used as an index for daily P.A. This is in contrast with other studies. Pařisková (1972) and Rutenfranz et al. (1974) found higher daily P.A. values for children with a high aerobic power than for those with a low aerobic power. However, the activity levels in these studies were based on information about leisure time and sport activities over a longer period of time. The fact that no relationship is found in our study can be the result of measuring daily P.A. over a period of only one day. A high intra-individual variation in the T.E.E. could mask the relationship between the two variables (Liu et al., 1978).

Another possible explanation could be the fact that T.E.E. is a combination of resting E.E. and E.E. from P.A. Therefore, T.E.E. might not be specific enough to be used as an indicator for physical activity. It was hypothesized that E.E. >50 and E.E. >75 are more specific in this respect. The calculation of both indices was based on the idea that especially these levels of P.A. (higher than 50 % or 75 % of the aerobic power) can have a training effect on the aerobic power. However, the relationship between both indices and the aerobic power was opposite to what was expected (Tables 3a and 4a). Boys and girls with a low aerobic power have significantly higher E.E. >50 values and also tend to have higher E.E. >75 values than children with a high aerobic power. The relative contribution of E.E. >50 and E.E. >75 to T.E.E. is higher for boys than for girls (Table 1). Therefore, it is less likely that systematic errors account for the discrepancy between E.E. indices and aerobic power levels. It is suggested that children with a low aerobic power are more active, relative to their lower level of aerobic power than children with a high aerobic power. Further study is required in this area.

Aerobic Power, Body Composition and Bloodlipids

It can be seen in Tables 3 and 4 that there is a relationship between aerobic power, body composition and the level of bloodlipids for this group of young children. In general children with a low aerobic power tended to be taller, weighed more and had a higher sum of skinfolds. Also the HDL/total cholesterol ratio was lower in this group. These findings are in agreement with those authors who have pointed out the negative relationship between aerobic power and percentage body fat and the positive relationship between percentage of body fat and the level of bloodlipids in adults (Albrink and Meigs, 1971; Montoye, 1975).

This relationship has been studied less intensively and systematically in children. Välimäki et al. (1980) found higher HDL levels in trained lean children compared with untrained children with higher percentage of fat. Gilliam et al. (1978) reported increase in HDL/total cholesterol ratio in 8-10-year-old girls following a 6-week P.A. program. Total cholesterol was reduced for 11- to 13-year-old obese girls in a 3-week exercise program, with a concomitant reduction of the body weight (Widhalm et al., 1978).

Aerobic Power and Dietary Factors

In a previous study (Saris et al., 1981) with 54 children ages 8-12 years, an analysis of the E.I. and the sources of energy revealed a higher intake in the high aerobic power groups. However, since the number of children in each age group was small, the results of boys and girls were not handled separately. The finding in the present study that boys have a higher aerobic power than girls (Table 1) suggests that there were more boys than girls in the high aerobic power groups in the previous study. The differences found in the previous study concerning energy and nutrient intake can thus possibly be explained as due to differences in sex rather than difference in aerobic power as such.

Although we must be careful with conclusions about energy and nutrient intake from the present study, considering the disadvantages of the method used, it seems that there are no clear indications that specific dietary factors are determinants for the level of aerobic power in this group of school children. Unfortunately, there are no data available from other studies related to this subject in well-nourished populations.

Conclusions

This study concerns the aerobic power and daily physical activity and some risk indicators such as body fatness, bloodlipids and nutrional habits.

Estimations of P.A. were made by assessing T.E.E. using 24-hour H.R. measurements. The data obtained for the T.E.E. and the specific activity indices E.E. >50 and E.E. >75 show that boys are more active than girls. These differences are also shown in the E.I. obtained with the 24-hour recall method. The level of E.I. was in disagreement with the T.E.E. for older children, suggesting that not all of the food stuffs were noted.

No clear differences were found between boys and girls with respect to the relationships between T.E.E. and the level of aerobic power. An attempt was made to relate P.A. to the level of aerobic power. The results gave no clear picture in this respect. More detailed studies are necessary.

A relationship was found, especially in the older children, between aerobic power, body fatness and level of bloodlipids. Children with a high aerobic power are leaner and have a higher HDL/total cholesterol ratio.

Finally, the results of the dietary habits, obtained by the 24-hour recall method, suggest that specific dietary factors are not related to the level of aerobic power in this age group.

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As part of the G.V.O.-project in Nijmegen, health education programs are being developed for kindergarten and elementary school. To investigate the effect these programmes have on attitude, behavior and physical health, a study is being conducted with a group of approximately 800 children. One of the themes handled in this program is physical activity. This thesis gives a report of a number of studies conducted within this project toward the aerobic power as indicator for physical performance capacity and daily physical activity.

The general area within which this study took place is discussed in *chapter 1*. A brief summary is given of the studies described in the literature in the area of the meaning of physical exercise and performance capacity especially for cardio-vascular aspects of adult health. Furthermore, the sparce data on this subject for children are summarized. Also discussed is the existence of only a small number of methods at the start of the study for measuring the aerobic power and the daily physical activity in young children. For this reason, the first part of this thesis deals with the development of methods for measuring these two aspects in children.

In *chapter 2* two experiments are reported with children to investigate the degree to which two submaximal exercise tests of short duration on the treadmill can give a good estimation of the aerobic power. The results showed that the group mean was correctly estimated, however, a great deviation from the actual measured values was possible for individual subjects.

In *chapter 3* the results are discussed of studies into the reliability and validity of 2 types of movement counters: the pedometer and the actometer. Both pieces of equipment are suitable for getting an impression of the physical activity in children. In view of the results, the actometer is preferable because it registers the intensity of the movements better than does the pedometer which mainly measures the number of movements. Extra attention should be paid to the calibration of both instruments.

In *chapter 4* the heart rate as a parameter for determining the intensity of energy expenditure during physical activity is discussed. This method is based upon the relationship between the heart rate and the energy expenditure, i.e. oxygen consumption, for each individual. The energy expenditure can be calculated from the heart rate which is measured during

daily activities and the relationship described above. Small light-weight recorders were developed and the method was validated. The following conclusions can be drawn:

- It is now possible to measure the heart rate of young children over a 24-hour period by means of a solid-state recorder without influencing the physical activity;
- The measurements of the average number of heartbeats per unit of time (for example, 1 minute) and those in which the heart rate is obtained from beat to beat time intervals over a 24-hour period, provide the same number of beats per heart rate level (for example, 100-125 beats per minute);
- When calculating the oxygen consumption from the heart rate, it is necessary to use a linear regression equation based upon measurements of heart rate and oxygen consumption for activities that are as close as possible to the activities to be measured with respect to type and posture;
- Prediction of energy expenditure during work by means of the heart rate provides mean values for the total group that are comparable to the actual measured values. There are, however, large deviations possible for individual subjects;
- The estimation of energy expenditure by means of the heart rate method should be preferred to the estimation of energy intake by means of the recall method for determining the level of energy metabolism during a 24-hour period in large groups of children;

The second part of this thesis deals with the results of aerobic power and physical activity. In *chapter* 5 the preliminary results are discussed of a study, currently under way, into the reference values of the aerobic power of children ages 4 to 18 years.

In *chapter 6* results are presented of the periodic studies of the G.V.O.-project into aerobic power, daily physical activities, and level of possible risk indicators for cardio-vascular diseases, body fatness, bloodlipids and nutrition at ages 6, 8 and 10 years. Some general conclusions from this part of the thesis are:

- The aerobic power of boys is, qua absolute levels as well as levels relative to body weight, greater than that of girls;
- There are no clear indications that the aerobic power of 4- to 18-year-

old Dutch children has decreased over the years;
- At ages 6, 8 and 10 years, boys are more active than girls;
- There is no relationship between the level of aerobic power and daily physical activity in 6 - 10-year-old children;
- There is no relationship between the level of aerobic power and quantitative or qualitative aspects of nutrition;
- There is a relation between the aerobic power on the one hand and the body fatness and the bloodlipid concentration on the other hand. Boys and girls with a low aerobic power had a higher percentage of fat and a lower HDL/total cholesterol ratio than children with a high aerobic power.

In het kader van het G.V.O.-project Nijmegen worden gezondheids- voorlichtingsprogramma's ontwikkeld voor het kleuter- en basisonderwijs. Om na te gaan in hoeverre deze programma's effect hebben op de attitude, gedrag en de lichamelijke gezondheid wordt onderzoek gedaan bij een groep van circa 800 kinderen. Eén van de thema's die in dit onderwijsprogramma wordt behandeld is lichamelijke activiteit. In dit proefschrift wordt verslag gedaan van een aantal onderzoekingen binnen dit project naar de dagelijkse lichamelijke activiteiten en het aeroob vermogen, als indicator voor het lichamelijk prestatievermogen.

In *hoofdstuk 1* wordt het algemene kader beschreven waarin deze studie geplaatst kan worden. Een kort overzicht wordt gegeven van de in de literatuur beschreven onderzoekingen over de betekenis van lichamelijke inspanning en het prestatievermogen voor vooral cardio-vasculaire aspecten van de gezondheid bij volwassenen. Tevens worden de schaarse gegevens hierover bij kinderen samengevat. Verder wordt ingegaan op het bestaan van slechts een gering aantal methoden bij de aanvang van deze studie, om het aeroob vermogen en de dagelijkse lichamelijke activiteiten bij jonge kinderen te meten. Reden waarom in het eerste gedeelte van dit proefschrift aandacht wordt besteed aan de ontwikkeling van methoden om beide aspecten bij kinderen te kunnen meten.

In *hoofdstuk 2* wordt verslag gedaan van een tweetal experimenten bij kinderen, om na te gaan in hoeverre met behulp van twee typen kortdurende submaximale inspanningstesten op de tredmolen een goede schatting gegeven kan worden van het aeroob vermogen. Uit de resultaten bleek dat het gemiddelde van een groep juist geschat wordt. Individueel gezien echter, zijn grote afwijkingen van de werkelijke waarde mogelijk.

In *hoofdstuk 3* worden de resultaten besproken van de onderzoekingen naar de betrouwbaarheid en validiteit van twee typen bewegingstellers: de pedometer en de actometer. Beide apparaten zijn geschikt om een indruk te krijgen van de lichamelijke activiteit bij kinderen. Gezien de resultaten gaat de voorkeur uit naar de actometer, omdat dit apparaat de intensiteit van de beweging beter registreert dan de pedometer, die overwegend het aantal bewegingen vastlegt. Extra aandacht dient besteed te worden aan de ijking van beide instrumenten.

In *hoofdstuk 4* wordt ingegaan op de hartfrequentie als grootheid om de intensiteit van het energieverbruik van de lichamelijke activiteit te bepalen. Deze methode is gebaseerd op de relatie per individu tussen de hartfrequentie en het energieverbruik, c.q. de zuurstofopname: deze wordt bepaald bij gestandaardiseerde vormen en intensiteiten van lichamelijke inspanning. Uit de hartfrequentie, die gemeten wordt bij de dagelijke activiteiten en de zojuist beschreven relatie, kan het energieverbruik van de activiteiten berekend worden. Kleine lichtgewicht hartfrequentie recorders werden ontwikkeld en de methode werd gevalideerd. De volgende algemene conclusies zijn te trekken:

- Het is thans mogelijk bij jonge kinderen met behulp van een solid-state recorder de hartfrequentie gedurende 24 uur te meten zonder dat de lichamelijke activiteit wordt beïnvloed;
- De meting van het gemiddeld aantal hartslagen per tijdseenheid (b.v. één minuut) en die waarbij de hartfrequentie verkregen wordt uit de slag tot slag interval tijden, gedurende 24 uur, geven hetzelfde aantal slagen per hartfrequentie niveau (b.v. 100-125 slagen per minuut);
- Bij de berekening van de zuurstofopname tijdens arbeid uit de hartfrequentie is het noodzakelijk een lineaire regressie vergelijking te gebruiken die gebaseerd is op metingen van hartfrequentie en zuurstofopname bij activiteiten die qua houding en soort zoveel mogelijk overeenkomen met de te meten activiteiten;
- Het voorspellen van het energieverbruik uit de hartfrequentie geeft per groep overeenkomstige gemiddelde waarden als die welke werkelijk gemeten zijn. Individueel zijn echter grote afwijkingen van de werkelijke waarde mogelijk;
- Voor de bepaling van de hoogte van het energiemetabolisme gedurende 24 uur bij grote groepen kinderen, geeft de schatting van het energieverbruik met behulp van de hartfrequentie methode meer valide gegevens dan de schatting van de energieopname met behulp van de recall-methode.

Het tweede gedeelte van dit proefschrift handelt over de resultaten van het onderzoek naar het aeroob vermogen en de lichamelijke activiteit.
In *hoofdstuk 5* worden de eerste resultaten besproken van een nog lopend onderzoek naar referentiewaarden van het aeroob vermogen van kinderen van 4 tot 18 jaar.

In *hoofdstuk 6* worden de resultaten gepresenteerd van de tussentijdse onderzoekingen binnen het G.V.O.-project naar het aeroob vermogen, de dagelijkse lichamelijke activiteiten en het niveau van enkele risico-indicatoren voor hart- en vaatziekten, percentage lichaamsvet, bloedlipiden en de voeding, op de leeftijd van 6, 8 en 10 jaar. Enkele algemene conclusies uit dit gedeelte van het proefschrift zijn:

- Het aeroob vermogen van jongens is zowel absoluut als gerelateerd aan het lichaamsgewicht groter dan van meisjes;
- Er zijn geen duidelijke aanwijzingen dat het aeroob vermogen van kinderen van 4 tot 18 jaar in de loop der jaren is achteruitgegaan;
- Op de leeftijd van 6, 8 en 10 jaar zijn jongens lichamelijk actiever dan meisjes;
- Er is geen verband tussen de hoogte van het aeroob vermogen en het niveau van de dagelijkse lichamelijke activiteit, zowel voor jongens als voor meisjes in de leeftijd van 6 - 10 jaar;
- Er is geen relatie tussen de hoogte van het aeroob vermogen en quantitatieve of qualitatieve aspecten van de voeding;
- Er is wel een verband tussen de hoogte van het aeroob vermogen enerzijds en het percentage lichaamsvet en de bloedlipiden concentratie anderzijds: jongens en meisjes met een laag aeroob vermogen hebben een hoog percentage vet en een lagere HDL/totaal cholesterol ratio dan kinderen met een hoog aeroob vermogen.

CURRICULUM VITAE

De auteur werd geboren op 17 augustus 1949 te Zwolle. Na het behalen van het diploma HBS-b aan het Thomas à Kempis Lyceum te Zwolle in 1967 begon hij in september van dat jaar met zijn studie aan de Landbouwhogeschool te Wageningen. In 1974 slaagde hij voor het ingenieursexamen met Voedingsleer als hoofdvak en Inspanningsfysiologie en Toxicologie als bijvakken.

Hij studeerde geneeskunde aan de Katholieke Universiteit te Nijmegen, waar het doctoraal examen en arts examen werden afgelegd in respectievelijk 1977 en 1979.

Sinds 1973 is hij part-time werkzaam bij het G.V.O.-project Nijmegen (projectleider Prof. K.G. König), waar het in dit proefschrift beschreven onderzoek grotendeels werd verricht. Dit gebeurde in nauwe samenwerking met de werkgroep Inspanningsfysiologie (hoofd Prof.Dr. R.A. Binkhorst) van de subfaculteit Geneeskunde der Katholieke Universiteit. Sedert 1980 is hij tevens part-time werkzaam binnen deze werkgroep.

STELLINGEN

I

Jongens zijn lichamelijk meer actief dan meisjes, ook al op de leeftijd van 6 tot 10 jaar.

Dit proefschrift, hoofdstuk 7.

II

De conclusie dat de lichamelijke conditie van de Nederlandse jeugd te wensen overlaat is onvoldoende gefundeerd in de Nota "Bewegingsarmoedig onderwijs" en wordt voor wat betreft het aeroob vermogen niet bevestigd in dit onderzoek.

- *Nota "Bewegingsarmoedig onderwijs". Jan Luiting Fonds, no. 35, Utrecht (1980).*
- *Dit proefschrift, hoofdstuk 6 en 7.*

III

Door middel van de hartfrequentiemethode is het mogelijk voor een groep het dagelijkse energieverbruik te bepalen.

Dit proefschrift, hoofdstuk 4.

IV

De relatie tussen het aeroob vermogen van kinderen en het dagelijkse energieverbruik, boven een niveau van respectievelijk 50 en 75 % van dit aeroob vermogen, dient nader onderzocht te worden.

Dit proefschrift, hoofdstuk 7.

V

Het onderzoek naar de regulatie van het energiemetabolisme dient gestimuleerd te worden.

VI

Lichaamsbeweging behoort nog steeds een belangrijk onderdeel te zijn van de behandeling van Diabetes Mellitus.

- *Allen, F.M.: Exercise. In: Total dietary regulation in treatment of Diabetes Mellitus. (F.M.Allen et al., eds.), Rockefeller Institute (New York, 1919).*
- *Richter, E.A. et al.: Diabetes and Exercise. Amer.J.Med. 70, 201 (1981).*

VII

Het argument "baat het niet, het schaadt ook niet", dat door veel sportlieden wordt gehanteerd bij het overmatig gebruik van wateroplosbare vitaminepreparaten, is onjuist.

Wise, A.: Nutrient Interrelationships. Nutr.Abstr.Rev. 50, 319 (1980).

VIII

Gezonde voedingsmiddelen bestaan niet.

IX

Met het oog op de volksgezondheid dient het bewerken van een volkstuin krachtig gestimuleerd te worden.

X

Resultaten van onderzoek bereiken een aantal doelgroepen met meer effect via voordrachten en artikelen in niet-vaktijdschriften dan via officiële wetenschappelijke publicaties. Bij de beoordeling van de output van werkgroepen dient daarmee ernstig rekening gehouden te worden.

XI

Voor een goed contact tussen de verschillende werkgroepen van een vakgroep is het gezamenlijk koffie drinken veruit te prefereren boven het frequent houden van vakgroep-, staf- of lunchvergaderingen.

XII

Politieke partijen, zoals ze nu functioneren, staan de democratie in de weg.

XIII

Bij de invoering van veel deeltijdarbeid en variabele werktijden voor ministers, mag niet worden uitgesloten dat er momenten zijn waarop een capabele ploeg aanwezig is.

Nijmegen, 18 februari 1982 W.H.M. Saris